2156

THE NIAGARA RIVER MUSSEL AND LEECH BIOMONITORING STUDY

OCTOBER 1992

Environment
Environnement
Ontario

27/10/92

ISBN 0-7778-0228-7

THE NIAGARA RIVER MUSSEL AND LEECH BIOMONITORING STUDY

Report prepared by:

L. Richman
Great Lakes Section
Water Resources Branch
Ontario Ministry of the Environment

OCTOBER 1992

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PIBS 2156
Log 92-2320-076

FOREWORD

Environment Ontario's biomonitoring study along the Niagara River in 1989 has provided background information for the development of the Niagara River Remedial Action Plan (RAP) currently under preparation. It is anticipated that the data collected from this study will be included in the 50% Loading Reduction Report which will be submitted by the Niagara River Toxics Secretariat to the Niagara River/Lake Ontario Coordination Committee.

This biomonitoring survey supports the Ministry's commitments to the Niagara River Toxics Management Plan.

Information provided by this study is part of an overall program to assess long-term trends in contaminant loadings from selected sources along the Niagara River.

This survey was repeated in 1991 with an additional 10 stations added to the survey design. The analytical results are not available yet.

ACKNOWLEDGEMENTS

This study was requested by the Niagara River Improvement Project Office of the Ministry of the Environment as a follow-up to the recommendations of the Niagara River Toxics Committee Report (NRTC, 1984) and to fulfil monitoring commitments under the Niagara River Toxics Management Plan (1987).

The author acknowledges the efforts of J. Anderson for planning the survey and G. Hobson for the actually field work. The author further acknowledges the efforts of Drinking Water Organics, Inorganic Trace Contaminants, and Trace Organics Laboratory Sections for the analysis of these samples.

The author expresses appreciation to: M. Walsh for his assistance in data analysis; P. Kauss and K. Suns for the information and data they provided ; P. Kauss, D. Boyd, T. Howell and A. McLarty for their constructive reviews of the manuscript.

EXECUTIVE SUMMARY

Summary of 1989 Results

Contaminants are often present in the water column at concentrations which are below the method detection limits, however, at these low concentrations they are still bioavailable and may have an impact on individual aquatic organisms as well as aquatic community structure. Biomonitoring studies indicate the presence of these contaminants, their sources and their availability to biota.

Freshwater mussels were placed in the Niagara River at 15 stations for three weeks. Upon retrieval mussels were processed and analysed for PCBs, organochlorine pesticides, chlorinated benzenes, polycyclic aromatic hydrocarbons (PAHs) and metals. Leeches were introduced to the river at six station for three weeks and analysed for chlorinated phenols. Sediment samples were collected at selected sites and analysed for organic and inorganic contaminants and polychlorinated dioxins and furans.

The 1989 data for mussels and leeches show that the majority of contaminants detected were found on the U.S. side of the river at the Pettit Flume in North Tonawanda, and in Niagara Falls at the 102nd Street landfill site, Occidental's Buffalo Avenue plant (sewer 003), and the mouths of Gill Creek and Bloody Run Creek. In almost all cases, with the exception of PAHs, contaminants were not detected in mussels introduced to the Canadian side of the Niagara River and at the Thunder Bay, Lake Erie control site. This suggests that for most contaminants, sources are within the Niagara River and not from Lake Erie.

Pesticides that were detected in mussel tissue collected from the American sites were present at low concentrations (range 2 - 120 ng/g). The compound α-BHC (the most ubiquitous isomer of technical grade BHC from which the pesticide lindane is extracted) was detected at almost all the sites on the American side. The highest concentration of α-BHC was detected in mussels exposed at Gill Creek.

PCB concentrations in mussels at 102nd Street, Occidental's sewer 003, Gill Creek, 60th Street sewer and Bloody Run Creek were higher than any of the other sites sampled and suggest important point source contributions of PCBs to the Niagara river. Concentrations in mussels placed at these sites were greater than the Canada-U.S. Great Lakes Water Quality Agreement specific objective for the protection of fish-eating wildlife, which is 100 ng/g.

The highest concentrations of most chlorinated benzenes and chlorinated industrial compounds tested (eg. 1,2,3,4-tetrachlorobenzene, pentachlorobenzene and hexachlorobenzene) were present in mussels placed at two sites: in the inlet at the Pettit Flume and at Occidental's sewer 003. Gill Creek was the only site identified as a source of hexachlorobutadiene relative to the other sites that were sampled.

Mussels at all of the American sites had PAHs present in their tissues and in almost all cases concentrations were higher than at Canadian sites.

In general, the most frequently detected PAHs in mussel tissue were benzo(b)fluoranthene, chrysene, fluoranthene, naphthalene, and pyrene.

Acenaphthene, fluoranthene, fluorene, pyrene, naphthalene and phenanthrene occurred sporadically in Balsam Lake mussels in 1989.

Mussels exposed at Occidental's sewer 003, Bloody Run Creek and Hyde Park had significantly higher concentrations ($p < 0.01$) of naphthalene than at other sites suggesting point source contributions of this compound.

Concentrations of benzo(b)fluoranthene in mussels at the Pettit Flume, Gratwick/Riverside Park and Gill Creek were significantly ($p < 0.01$) higher than at all the other sampling stations.

Chrysene, pyrene and fluoranthene in mussels exposed at the Pettit Flume, Wheatfield, Occidental's sewer 003 and the 60th Street sewer were significantly higher than concentrations in mussels placed at all other sites.

With the exception of copper, nickel and mercury concentrations of inorganic contaminants in caged mussels (from all sites) were not significantly different than the Balsam Lake mussels and the control mussels introduced at Thunder Bay, Lake Erie. Concentrations of copper were significantly higher ($p < 0.0001$) in mussels at the Pettit Flume and Gill Creek than all other sites and concentrations of mercury were significantly higher ($p < 0.0004$) in mussels at the 102nd Street landfill site than at most other sites. The highest nickel concentrations were found in mussels placed at Gill Creek.

Polychlorinated dioxins and furans were detected in surficial sediment collected from the 102nd Street landfill site and the Pettit Flume. Concentrations in sediment collected from the Pettit Flume were 100 to 1000 times higher than concentrations detected in sediment collected near the 102nd Street landfill. The Pettit Flume is still an important source of dioxins and furans to the Niagara River.

Leeches were placed at five stations suspected of being potential sources of chlorinated phenols to the Niagara River. Leeches are particularly good monitors of these compounds. Chlorinated phenols were detected in leeches exposed to Frenchmans

Creek and the Pettit Flume. They were not detected at the other stations sampled; (Gratwick/Riverside Park and Niagara-on-the-Lake).

Contaminant Trends Through Time

The study design for this survey is particularly useful for identifying sources of contaminants and to determine the relative magnitude of a contaminant source when compared spatially with other sources on the Niagara River. The use of caged mussels in contaminant trend-through-time analysis is limited however; and should be approached cautiously since the mussel data represent short term uptake during their limited (three week) exposure period. The data should only be used qualitatively to indicate large changes in contaminant loadings and bioavailability over time.

Concentrations of organochlorine pesticides, PCBs, chlorinated benzenes, chlorinated industrial compounds and PAHs in mussels in 1989 at all sites were consistent with concentrations present in mussels in previous surveys in 1983, (1985 for Pettit Flume), and 1987 with the following exceptions:

Pettit Flume - 1,2,3,4-tetrachlorobenzene was lower in 1989 when compared with 1985 data

Occidental's sewer 003 -

Hexachlorobenzene increased in 1989 relative to 1987 (concentration in mussel tissues were similar to 1983).

2,3,6-trichlorotoluene and 2,4,5-trichlorotoluene increased since 1983 and 1987.

Concentrations of fluoranthene, pyrene, benzo(a)anthracene and benzo(b)fluoranthene were all lower in 1989 than in 1987.

Concentrations of mirex in 1989 have decreased compared with 1987 values but are similar to 1983 values. High variability between replicates precludes any trend through time analysis.

Gill Creek -

Although considerable variability exists among sample replicates collected in 1983, 1987 and 1989, an overall decrease between years, and in particular between 1983 and 1989, suggests a downward trend in the bioavailability of PCBs at Gill Creek. This may be an indication that past remedial activities at Gill Creek are beginning to have a positive effect.

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INTRODUCTION

The Niagara River is 64 km long and flows from Lake Erie to Lake Ontario at an average flow of 5700 m^3/s (Niagara River Toxics Committee (NRTC) 1984). The river provides drinking water, power generation, municipal and industrial water supplies, recreation and tourism opportunities to a population of more than one million Canadian and American people.

The Niagara River has a long history of contamination due to human activities which are incompatible with the long-term concept of responsible environmental use (Durham and Oliver 1983). The environmental agencies of Canada, the United States, Ontario and New York recognize that the majority of the pollution in the Niagara River comes from New York. Most of the urban and industrial development is located in Buffalo, Tonawanda and Niagara Falls, New York. The discharge of contaminants, particularly toxic chemicals from outfalls and hazardous waste landfills in New York has greatly influenced the environmental quality of the Niagara River (Elder *et al.* 1981; NRTC 1984; Gradient Corp./Geotrans Inc. 1988; Raven 1991). There are over 100 municipal and industrial point source discharges to the river including 29 which were described as significant sources of contaminants by the NRTC. The New York Department of Environmental Conservation identified over 300 hazardous waste sites in Erie and Niagara counties, New York, that are potential contaminant sources to the Niagara River. The contaminants include hazardous chemicals such as mirex, PCBs, organochlorine pesticides such as BHC, chlorobenzenes, chlorophenols, chlorotoluenes, polycyclic aromatic hydrocarbons (PAH), and polychlorinated dioxins and furans (Interagency Task Force on Hazardous Waste 1979; Elder *et al.* 1981).

The extent of industry on the Canadian side of the Niagara River is considerably less than on the U.S. side. Ontario's loadings of EPA Priority Pollutants represents about 11% of the total point source loading to the Niagara (NRTC 1984). The majority of the contaminants originating from Ontario are metals (Niagara River Remedial Action Plan Stage 1 1992). Eight of the 23 point sources in Ontario were designated as significant sources of contaminants. Only five waste sites have been identified as a possible source of contaminants to the river (Monenco Consultants Limited 1991). In contrast to waste sites on the U.S. side of the river, these five sites do not contain organics or persistent toxic chemicals.

The Niagara River Toxics Committee (NRTC) was established in 1981 by the federal governments of Canada and the United States and the province of Ontario and state of New York. This committee was responsible for coordinating and gathering information concerning the environmental status of the Niagara River and determining the point and non-point source loadings of toxic chemicals to the river. This information was reported in 1984 in the Report of the Niagara River Toxics Committee (NRTC, 1984).

In 1987 the four agencies (represented by Environment Canada, the Ontario Ministry of the Environment, the U.S. Environmental Protection Agency and the New York Department of Environmental Conservation) developed the Niagara River work plan and signed a Declaration of Intent for the Niagara River. The Declaration of Intent commits the agencies to a 50% reduction of toxic contaminant loadings from point sources to the Niagara River by 1996. The work plan and the Declaration of Intent together form the Niagara River Toxics Management Plan (NRTMP). Ten persistent toxic chemicals of concern were targeted by the plan and these are highlighted in this biomonitoring report.

The data generated by the 1989 Niagara River Biomonitoring survey augments ongoing Niagara River Toxics Management Plan programs by providing information on contaminant levels in the river between Fort Erie and Niagara-on-the-Lake.

Contaminants are often present in the water column at concentrations which are below readily available method detection limits, however, they are still bioavailable and may have an impact on individual aquatic organisms and aquatic community structure. Biomonitoring studies indicate the presence of these contaminants, their sources and their availability to biota.

Freshwater mussels (*Elliptio complanata*), filamentous algae (*Cladophora glomerata*) and young forage fish (*Notropis hudsonius*) have been routinely used as contaminant monitors on the Niagara River since 1980. The use of leeches (*Nephelopsis obscura*) as biomonitors for chlorinated phenols was initiated in the Niagara in 1987 because of their ability to effectively accumulate these compounds (Metcalfe and Hayton 1989).

This report presents the results of the 1989 mussel and leech biomonitoring survey. Caged mussels and leeches were exposed to the Niagara River for three weeks and then the tissues were analysed for a variety of contaminants. The study was designed to identify sources of contamination along the Niagara River. The results are useful to spatially compare the relative contribution of contaminants to the river from individual point and non-point sources and to assess, in general, temporal trends. Detailed analysis of contaminant loadings is not possible due to the short (three week) exposure period of the mussels and leeches. The main focus of the study is source identification and their relative contribution of individual contaminants.

When the non-point sources such as hazardous waste sites are remediated by containment of contaminants or contaminant removal through various remedial action programs, the biomonitoring study will be particularly useful to determine if these sites are still leaching contaminants into the river.

METHODS

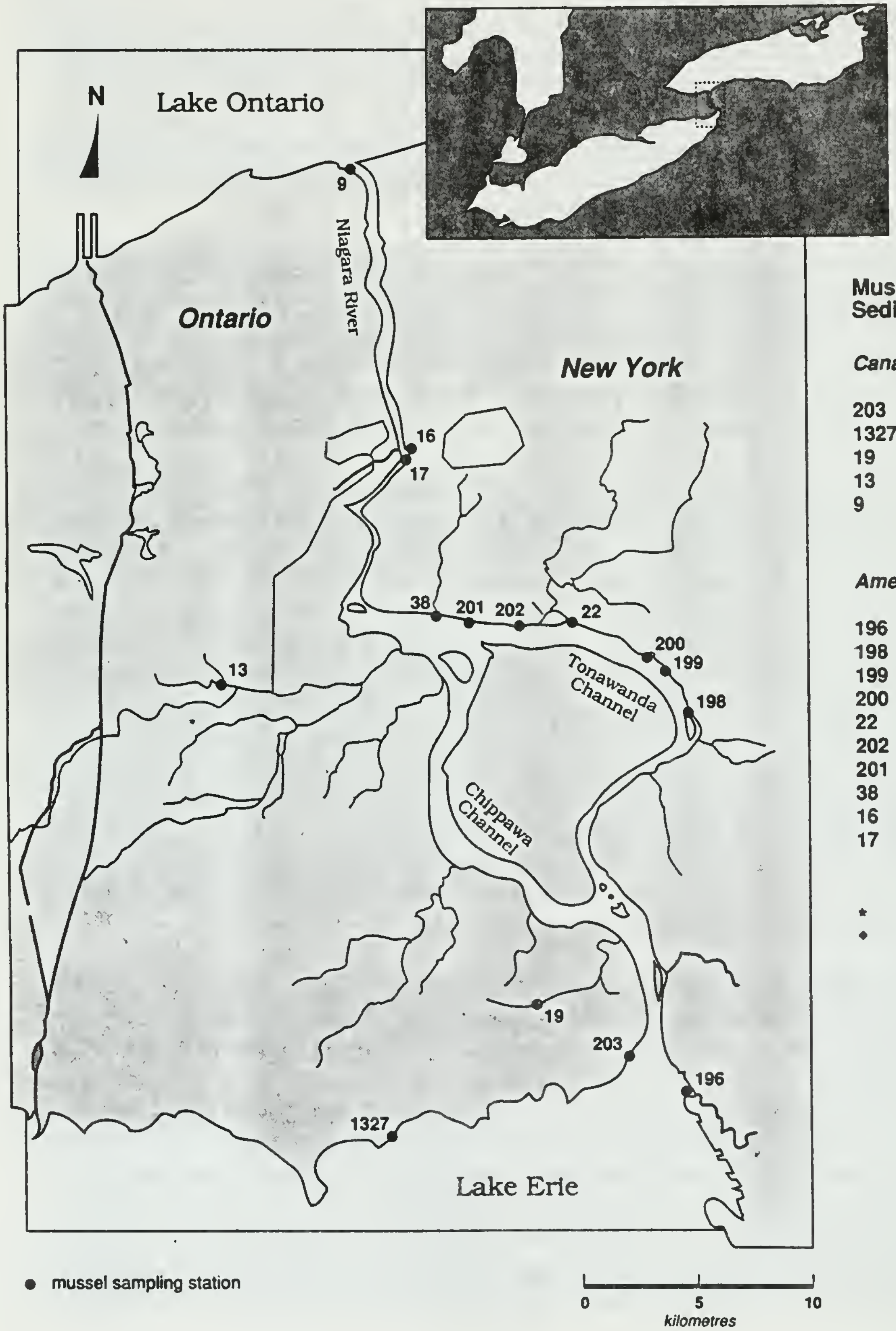
Caged mussels were placed in the Niagara River at 16 sampling stations in July, 1989 for three weeks (Figure 1). Sampling stations were located at the mouth of several tributaries and near known industries and disposal sites on the Canadian and American side of the river. Station location followed that of previous surveys (1983, 1987, and a special study in the Pettit Flume in 1985). The cages were usually placed within five metres from shore. The study design is intended to obtain results which represent contamination from shore based sources rather than ambient river conditions.

The mussels (*Elliptio complanata*) used for the study were diver-collected from Balsam Lake, a relatively uncontaminated lake in Ontario (Victoria County). The mussels were placed in buckets lined with clean bioassay (food-grade) bags partially filled with lake water for transportation. The bags were sealed with air trapped inside and rapid temperature fluctuations were avoided. Three random replicate samples of these mussels were submitted for tissue analysis to determine initial concentrations of contaminants.

At each station five mussels were placed in each of three (30 x 45 cm constructed of 1.25 cm galvanized mesh poultry netting) envelope-shaped cages. A nylon rope was attached to the cages and then anchored to the river bottom with a cement block. Cages were also anchored to the bottom using pegs or rocks and sometimes tied off a shoreline structure in a location which would likely not be disrupted during the course of the study. Mussels were retrieved after 21 days. They were immediately shucked, excess water was drained and the soft tissues were individually wrapped in hexane-rinsed aluminum foil and placed in a plastic bag. Tissues were sent for analysis of organic compounds such as organochlorine pesticides, PCBs, chlorinated benzenes and PAHs (Appendix Table A1). Mussels analysed for metals (arsenic, cadmium, copper, mercury, manganese, nickel, lead, selenium and zinc) were placed in plastic bags without foil. All samples were stored on ice during transport to the Environment Ontario laboratory in Rexdale, Ontario and then stored at -20 ° C prior to analysis. Analytical procedures followed the methodology outlined in the Handbook of Analytical Methods for Environmental Samples (MOE 1983). All results are reported on a wet weight basis. There are three replicates per station.

Forty-five leeches were suspended in cages at five stations (Figure 1) along with mussel cages and analyzed for chlorinated phenols (Appendix Table A1). Stations were located in areas suspected of being a source of these compounds. Leech cages were cylindrical in shape, 35 cm long x 15 cm in diameter and were constructed by 10 x 10 mesh (four spaces per linear cm) stainless steel wire cloth having a wire diameter of 0.064 cm and opening of 0.191 cm. The overlapping edges were woven together with stainless steel wire and the ends were capped with polyethylene plugs which had been presoaked in a cleaning solution to remove any soluble organic compounds. The plugs were secured with stainless steel gear clamps. The leeches were obtained from a Toronto bait shop and originated from a lake in Michigan or Wisconsin. Leeches were maintained in food-grade plastic-lined buckets with five litres of water for transportation to the study area. The head

Niagara River biomonitoring stations, 1989



Mussels, Leeches and Sediment Stations

Canadian Sites

203	Fort Erie at Robertson St,
1327	Thunder Bay
19	Frenchmans Cr. at Durez ◆*
13	Thompsons Cr. (mouth)
9	Niagara-on-the-Lake *

American Sites

196	Buffalo R.
198	Pettit Flume * ◆
199	Gratwick / Riverside Park *
200	Wheatfield *
22	102nd St. ◆
202	60th St. Sewer
201	Occidental Sewer 003
38	Gill Cr.
16	Hyde Park
17	Bloody Run Cr.

*	Leech sampling stations
◆	Sediment sampling stations

space in the buckets were filled with air, which was renewed daily, and were stored at ambient temperature.

Leeches were exposed in the river for 21 days. When the cages were retrieved, three replicate samples (each a composite of 10 to 15 individuals) from each site were wrapped in hexane-rinsed aluminum foil and stored on ice during transport to the Environment Ontario laboratory in Rexdale. The samples were then frozen at -20 °C prior to analysis.

Surficial sediment samples (top 3 cm) were collected from the Pettit Flume (two sites), Thompsons Creek and 102nd Street Landfill site using a Shipek sampler and analysed for metals, organochlorine pesticides, PCB's, chlorinated benzenes and PAHs. One composite sample was submitted from each site.

Mussels and surficial sediment from three stations (Pettit Flume (2) and 102nd Street landfill site) were analysed for polychlorinated dioxins and furans. These stations had high dioxin and furan concentrations in mussels and sediment in previous surveys. Unfortunately the analyses of the mussel tissues were withdrawn due to destruction of the samples during a freezer breakdown, so only sediment results are reported here.

Data Analysis

All mussel and sediment data were log transformed using natural logarithms prior to statistical analysis.

Mean inorganic contaminant concentrations in mussels were compared among stations using a one way ANOVA. The Tukey significant difference test was applied to test station differences and Dunnetts two-tailed t-test was used to determine if contaminant concentrations in mussels at each station were significantly different from the control station at Thunder Bay, Lake Erie or from the Balsam Lake mussels. Increases in contaminant concentrations in mussel tissue exposed to the Niagara River when compared with the controls would indicate that sources of contaminants were present in the river.

Mean organic contaminant concentrations in mussels were compared between stations using the SAS LIFEREG procedure (SAS Institute Inc. 1988). This procedure performs the Likely Ratio Test. Since organic contaminant concentrations in mussels were frequently below the limits of detection established by the analytical laboratory, the estimation of the mean and standard deviation was problematic. The Likely Ratio Test was, therefore, used to derive the test statistics and determine if there was a significant difference in contaminant levels within the study area. The Bonferoni confidence intervals were calculated to test significant differences between stations (SAS Institute Inc. 1988).

RESULTS AND DISCUSSION

The freshwater mussel, *Elliptio complanata*, is a filter feeder, feeding on plankton and detritus and will accumulate contaminants directly from the water column and from particulate matter. This method of feeding renders the mussel a good biomonitor since contaminants tend to partition between the dissolved phase and the solid phase where they become associated with sediment or suspended particulates through adsorptive processes. Mussels can integrate short term fluctuations in contaminant levels and, accordingly, tissue concentrations reflect short term contaminant pulses which may not be detected by routine water quality monitoring (Muncaster *et al.* 1989; Metcalfe and Charlton 1990; Kauss and Hamdy 1991; Lobel *et al.* 1991). The tendency for persistent contaminants to accumulate in the tissue or lipids of biota enable the detection of these compounds which are frequently present below method detection in water.

The data in this report are best used to identify contaminant sources and the relative contribution of contaminants to the river from individual sources. This study design is particularly useful to determine if non-point sources such as hazardous waste sites continue to leach contaminants to the river once site remediation has been completed.

The use of caged mussels in contaminant trend-through-time analysis is limited and should be approached cautiously since the mussel data represent short term uptake (i.e during the three week period of exposure). The mussel tissue contaminant concentrations are influenced by immediate changes in their environment and reflect changes in contaminant concentrations in the water column (Foster and Bates 1978; Muncaster *et al.* 1989; Metcalfe and Charlton 1990; Kauss and Hamdy 1991; Lobel *et al.* 1991), therefore, if pollutant loadings are reduced or increase during the three week exposure time, the mussel data will reflect this change in loadings. The tissue concentrations in the mussels, however, are unlikely to represent the overall (yearly) contaminant loading to that site over the long-term, particularly if loadings fluctuate over time.

At times considerable within-site variability in tissue contaminant concentrations can occur (Kauss and Angelow 1988; Tessier *et al.*1989; Lobel *et al.*1989; Anderson *et al.* 1991). Individual mussels at a site may stop filtering and isolate themselves from their environment or the physiological condition of a mussel at a site might affect contaminant uptake efficiency. Variability between (and within) sampling events may also be due to changes in water temperature or water levels, sex, size, growth rates etc. (Neff and Anderson 1975; Phillips 1980; Kauss and Angelow 1988; Green *et al.*1989; Lobel *et al.* 1989; Lobel *et al.* 1990). This must be acknowledged when trying to assess trends in contaminant loadings to the river. These qualifiers require that the data only be used qualitatively to indicate large changes in contaminant loadings and bioavailability over time. The nature of the survey design and data does not allow for quantitative interpretation of loading reductions or increases.

PCBs AND ORGANOCHLORINE PESTICIDES

Analysis of Balsam Lake mussels for contaminants show that all compounds tested were below method detection with the exception of α-BHC which was present in all three replicates at a mean concentration of 3 (Standard Deviation SD 0.58) ng/g.

PCBs and organochlorine pesticides were not detected in caged mussels introduced on the Canadian side of the river with the exception of one replicate at Niagara-on-the-Lake and at Thompsons Creek. Trace concentrations (2 ng/g) of p,p'-DDE were detected at these two stations.

The eight pesticides detected in mussel tissue collected from the American sites (p,p'-DDE, p,p'-DDD, p,p'DDT, γ-chlordane, α-chlordane, α-BHC, β-BHC, mirex), were present at low concentrations (Table 1). The compound α-BHC (the most ubiquitous isomer of technical grade BHC from which the pesticide lindane is extracted) was detected at almost all the sites on the American side. The highest concentration of α-BHC (120 ng/g) was detected in mussels deployed at Gill Creek (Figure 2). Spottail shiners collected from Gill Creek in 1985 also had the highest concentration of α-BHC when compared with samples from other stations in the Niagara River (Suns *et al.* 1991). Concentrations of α-BHC in the sediment at the mouth of Gill Creek ranged from 1.2 to 440 *u*g/g (New York State Department of Environmental Conservation 1992), which explains the presence of this compound at this site. Loadings of α-BHC from the Niagara River to Lake Ontario were significantly higher at Niagara-on-the-Lake in water and suspended sediment in 1988/89 when compared with loadings from Lake Erie to the Niagara River at Fort Erie suggesting sources of α-BHC in the Niagara River (Niagara River Data Interpretation Group, River Monitoring Committee 1990). Some of these sources were confirmed by the biomonitoring data. This compound has been identified as a Priority Toxic Chemical of Concern for surveillance in the Niagara River by the NRTC (NRTC 1984).

Concentrations of organochlorine pesticides in mussels in 1989 were consistent with concentrations present in mussels in previous surveys in 1983 and 1987 with the exception of mirex (Kauss 1987 unpublished data; Anderson *et al.* 1990). Mirex has been detected in mussels at Occidental's sewer 003 since the first survey in 1983; however, concentrations have changed with each survey. In 1983, concentrations in tissues from three replicate mussels were all low averaging 16 (SD 14) ng/g. In 1987, they increased considerably to 167 (SD 60) ng/g. In 1989 concentrations were similar to the 1983 values: mirex was not detected in two of the mussels analysed and one mussel had 40 ng/g. The presence of mirex in waters downstream of the outfall suggests that residues from previous operations at the facility are still leaching into the river, either from surrounding landfills, or from historically-contaminated equipment. Occidental Chemical Corporation (formerly Hooker Chemical and Plastics Corp.) was the sole producer of mirex. Sales began in 1959 (Interagency Task Force on Hazardous Waste 1979). The use of mirex has been limited since 1976 by Canadian and U.S. legislation because of its environmental impacts.

Table 1. Mean (+/- Standard Deviation) Concentrations (ng/g wet weight) of Organochlorine Pesticides and PCBs in Mussels Introduced to the Niagara River for Three Weeks, 1989. If one or more samples were below the MDL the range was provided in place of the mean.

Sampling Station	α BHC	β BHC	δ BHC	α Chlordane ♦	γ Chlordane ♦	Mirex ♦
MDL	1	1	1	2	2	5
Canadian Sites						
Fort Erie	.	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.	.
Thompsons Creek	.	.	.	.	.	.
NOTL	.	.	.	.	.	.
American Sites						
Buffalo River	.	.	.	.	.	.
Pettit Flume (site A)	(.) - 4	.	.	(.) - 4	(.) - 7	.
Pettit Flume (site B)	3 +/- 1.1	.	(.) - 2	5 +/- 0.6	6 +/- 1.5	.
Gratwick/ Riverside Park	.	.	.	.	.	.
Wheatfield	.	.	.	.	.	.
102nd Street	15 +/- 2.9	(.) - 5	(.) - 3	.	(.) - 5	(.) - 45
60th St. Sewer	3 +/- 0.0	.	(.) - 2	.	.	.
Occidental 003	6 +/- 4.6	4 +/- 2.3	(.) - 2	(.) - 7	31 +/- 16.4	(.) - 40
Gill Creek	47 +/- 63.2	11 +/- 8.5	.	.	.	.
Hyde Park	.	.	.	.	.	.
Bloody Run Creek	3 +/- 1.0	.	.	.	.	(.) - 50

Table 1 continued

Sampling Station	pp'-DDD ♦	pp'-DDE ♦	pp'-DDT ♦	Octachlorostyrene ♦	Total PCBs ♦	% Lipid
MDL	5	1	5	1	20	
Canadian Sites						
Fort Erie	.	.	.	.	.	1.03 +/-0.2
Thunder Bay, Lake Erie	.	.	.	.	.	1.1 +/- 0.2
Frenchmans Creek	.	.	.	.	.	1.2 +/- 0.2
Thompsons Creek	.	(.) - 2	.	.	.	1.1 +/- 0.4
NOTL	.	(.) - 2	.	.	.	0.88 +/- 0.3
American Sites						
Buffalo River	9 +/- 4	.	.	.	(.) - 60	1.02 +/- 0.3
Pettit Flume (site A)	.	(.) - 2	.	6 +/- 1.7	60 +/- 17.3	1.23 +/- 0.4
Pettit Flume (site B)	.	.	(.) - 8	5 +/- 0.0	90 +/- 10.0	1.18 +/- 0.4
Gratwick/ Riverside Park	.	.	.	.	.	1.2 +/- 0.3
Wheatfield	.	.	.	.	.	0.34 +/- 0.3

Sampling Station	pp'-DDD ♦	pp'-DDE ♦	pp'-DDT ♦	Octachlorostyrene ♦	Total PCBs ♦	% Lipid
MDL	5	1	5	1	20	
102nd Street	.	(.) - 27	.	(.) - 2	(.) - 400	0.67 +/- 0.3
60th St. Sewer	.	(.) - 8	.	.	(.) - 500	1.57 +/- 0.2
Occidental 003	8 +/- 0.6	(.) - 8	12 +/- 0.6	17 +/- 2.9	130 +/- 104.4	0.28 +/- 0.2
Gill Creek	.	.	.	23 +/- 10.0	(.) - 650	1.12 +/- 0.34
Hyde Park	.	(.) - 2	.	(.) - 4	.	0.17 +/- 0.12
Bloody Run Creek	.	7 +/- 5.6	.	(.) - 10	(.) - 220	0.18 +/- 0.03

"." Compound was below the method detection limit.

For all sampling sites n = 3, with the exception of 102nd Street where n = 5.

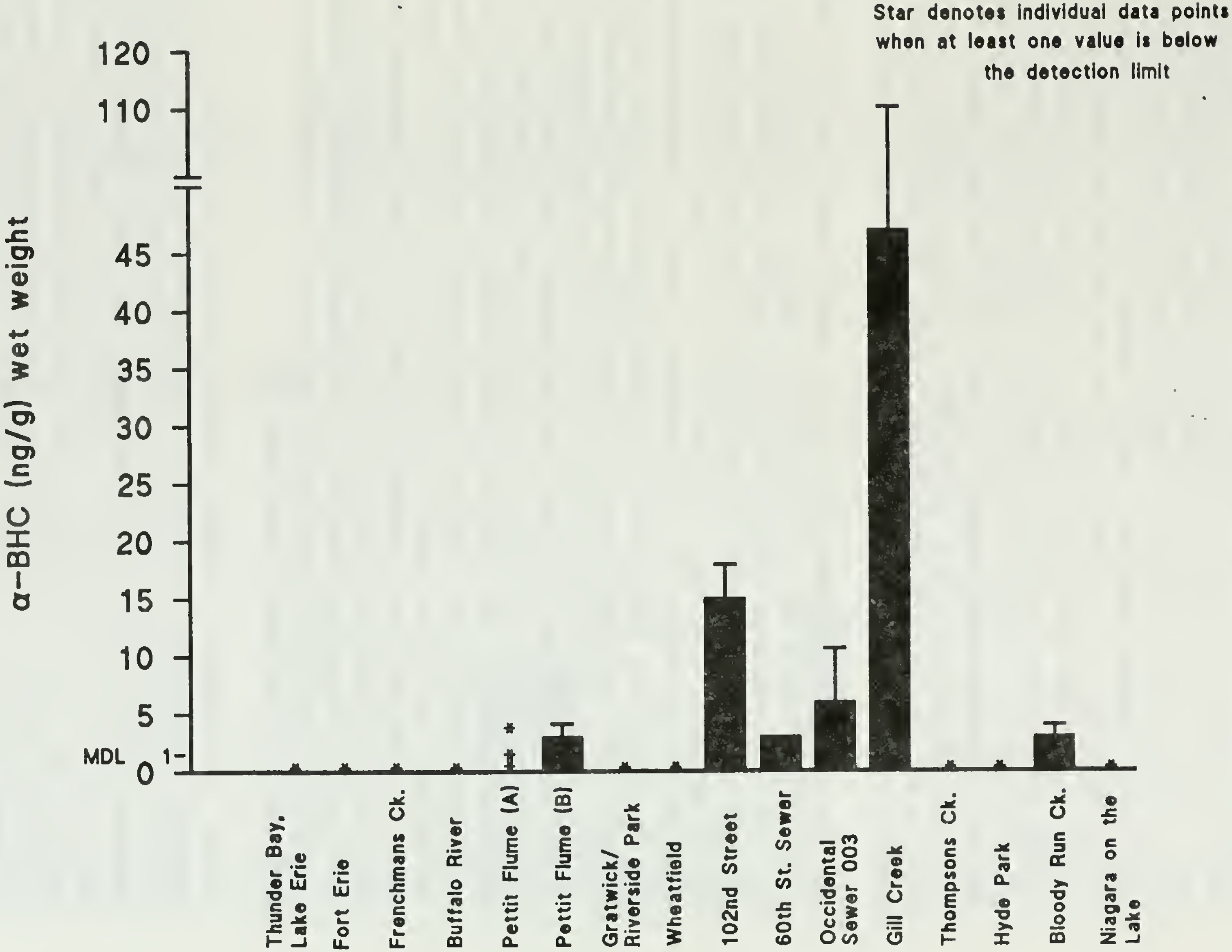
Site A = Within the contaminated Inlet   Site B = Just outsite the Inlet

♦ Priority Toxic Chemicals of Concern - Niagara River Toxics Management Plan.

NOTL : Niagara-on-the-Lake
MDL : Method detection limit

Aldrin (♦), Heptachlor (♦) and op-DDT were not detected in any samples analysed.

Fig.2: Mean Concentration of α-BHC in Mussels, Niagara River, 1989



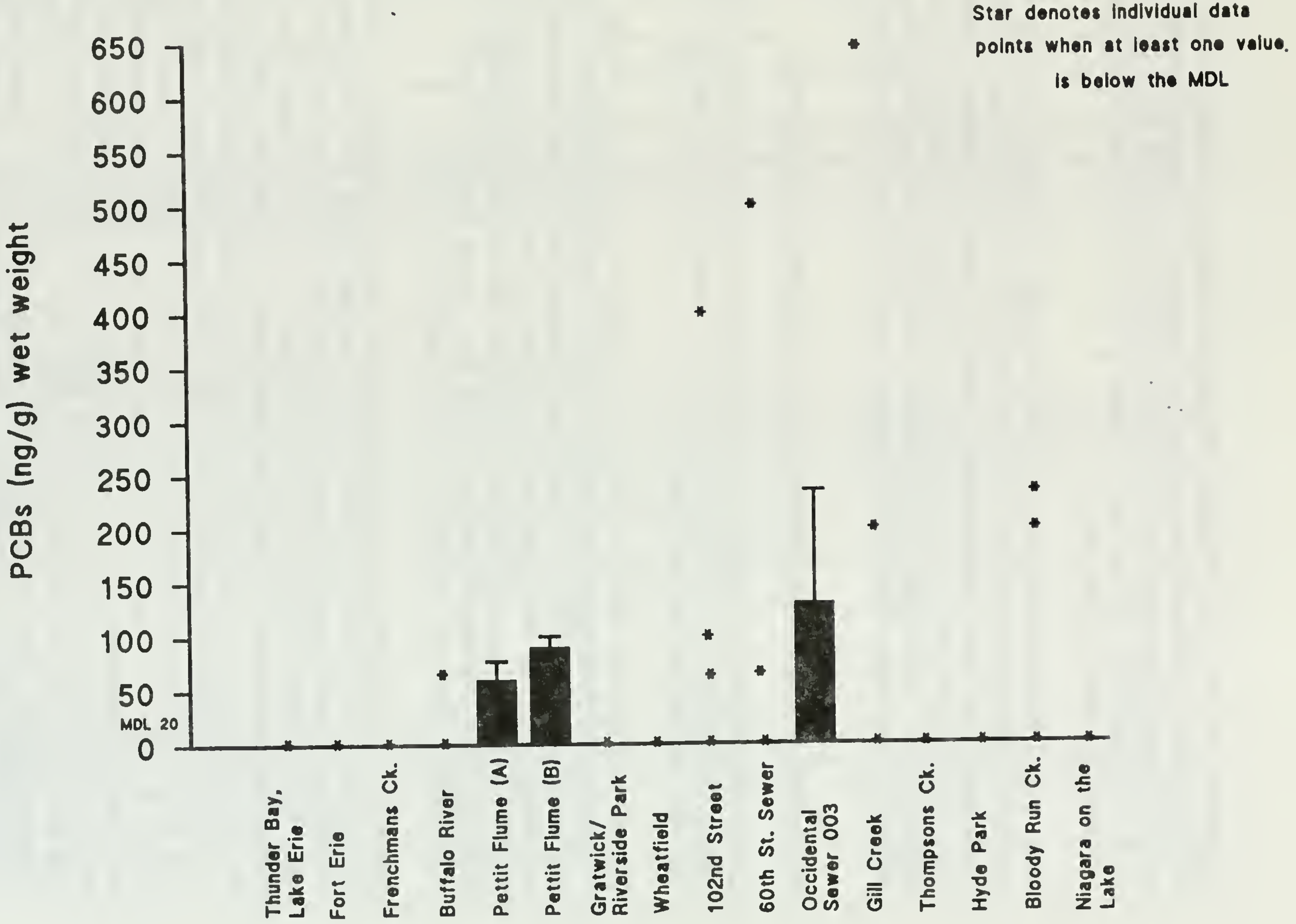
Star denotes individual data points when at least one value is below the detection limit

Trace concentrations of mirex were also detected in mussels at the 102nd Street landfill site (one mussel had 45 ng/g) and at Bloody Run Creek (two samples contained 50 ng/g) in 1989. In 1983 mirex was also detected in mussels at Bloody Run Creek at 7 (SD 6) ng/g. Mirex was not detected in mussels exposed at 102nd Street in the 1983 and 1987 surveys. Similar results were found in spottail shiners (Suns, unpublished data. 1991) at 102nd Street, where mirex was not detected in 1982 and 1987 but was detected in 1990. Hooker Chemical and Plastics Corp. owned a portion of the landfill and may have deposited mirex in the site during its operation. The presence of mirex in mussels and spottail shiners is an indication that mirex is leaching from the landfill. In 1990, mirex was detected in spottail shiners collected at all sites in the lower river, including Bloody Run Creek and Niagara-on-the-Lake. The variability in the mussel data within a site does not allow for any trend through time analysis; however, the presence of mirex at these locations confirms that the Niagara river is still a source of mirex to Lake Ontario.

High concentrations of PCBs were present in mussels exposed at the 102nd Street landfill site, Occidental's sewer 003, Gill Creek, 60th Street sewer and Bloody Run Creek (Figure 3). There is no statistical difference in PCB concentrations between these sampling locations because of high within-site variability. PCB concentrations at these sites were higher than any of the other sites sampled and suggest important point source contributions to the Niagara river. Concentrations in mussels at these sites were greater than the Canada-U.S. Great Lakes Water Quality Agreement specific objective for the protection of fish-eating wildlife, which is 100 ng/g. PCBs were also consistently detected in spottail shiners at concentrations greater than 100 ng/g at 102nd Street and Gill Creek (K. Suns unpublished data 1992) two of the five stations above where fish were collected. The PCBs detected at 102nd Street, Occidental's sewer 003 and Bloody Run Creek resembled the Aroclor 1254/1260 while PCBs detected at Gill Creek and the 60th Street sewer resembled Aroclor 1248. All these sampling locations are influenced by contaminants leaching from waste sites. Bloody Run Creek was contaminated by the Hyde Park Waste site which contained PCBs, as did the 102nd Street landfill site (Raven 1991). Both these sites have a history of health and environmental problems (Interagency Task Force on Hazardous Waste 1979). Plant effluent, contaminated groundwater and several waste sites are known to contribute contaminants (including PCBs) to Occidental's sewer 003 (Geologic Testing Consultants 1989).

Overall, concentrations of PCBs in mussels have been consistent over time (when compared with 1983 and 1987 data) at all stations with the exception of Gill Creek. Gill Creek has received contaminants from chemical operations at Olin and Dupont and was historically a known PCB "hot spot" (Interagency Task Force on Hazardous Waste 1979; Raven 1991), with concentrations of PCBs in the sediment near the mouth of Gill Creek ranging from 20 to 10,700 ug/g (New York State Department of Environmental Conservation 1992). However; mussel data show that concentrations in the water may be decreasing. In 1983 the mean PCB concentration of three mussels was 1,893 (SD 566) ng/g; in 1987 it was 935 (SD 163) ng/g and in 1989 the median value was 200 ng/g (individual concentrations in the three mussels were 650, 200 ng/g and below the method

Fig. 3: Mean Concentration of Total PCBs in Mussels, Niagara River, 1989



Star denotes individual data points when at least one value is below the MDL

reporting limit in the third mussel). Although considerable variability exists within a sampling period, this overall decrease between years, and in particular between 1989 and 1983, suggests a downward trend in the bioavailability of PCBs at Gill Creek. This may be an indication that past remedial activities in 1981 at Gill Creek (NYDEC 1991) are beginning to have a positive effect.

Mirex and PCBs are listed as Priority Toxic Chemicals of Concern by the NRTMP and both are targeted for the 50% reduction in loadings to the Niagara River by 1996. These compounds were found to be significantly higher in suspended sediment at Niagara-on-the-Lake than at the Fort Erie sampling station in the 1988/89 sampling period, indicating sources within the Niagara River (Niagara River Data Interpretation Group, River Monitoring Committee 1990). The biomonitoring results identify some of these sources.

CHLOROBENZENES AND CHLORINATED INDUSTRIAL COMPOUNDS

Chlorinated benzenes and other chlorinated industrial compounds were not detected in Balsam Lake mussels or in mussels at any of the Canadian sites including Thunder Bay, Lake Erie and the Fort Erie site (Table 2).

Of the 11 compounds tested for, nine were detected in mussels exposed at the Pettit Flume, and all but three were detected in mussels at Gill Creek, Occidental's Sewer 003 and 102nd Street landfill site. 1,2,3,4 tetrachlorobenzene was the only compound detected at Gratwick/Riverside Park. It was also detected at the 60th Street sewer, Hyde Park and Bloody Run Creek. Several chlorinated benzenes were detected at Bloody Run Creek. The only other compound detected at the 60th Street sewer and Hyde Park was pentachlorobenzene and hexachlorobenzene respectively (Table 2).

The highest concentrations of most contaminants tested were present in mussels placed at two sites in the inlet at the Pettit Flume. The Pettit Flume is a storm sewer which receives waste water from the Occidental Chemical Corp. Durez division and surrounding hazardous waste sites (Geologic Testing Consultants LTD. 1984). These sites were filled with waste products which included chlorinated phenols, chlorotoluene, other organic and inorganic compounds and phenol tar containing chlorinated benzenes (Interagency Task Force on Hazardous Waste 1979; Raven 1991). Chlorinated benzenes have also in the past been identified in the effluent from the Occidental Chemical Corporation, Durez Division in North Tonawanda (NRTC Report, 1984). Mussels from the two Pettit Flume sites had significantly ($p < 0.01$) higher mean concentrations of 1,2,3,4-tetrachlorobenzene (170 (SD 69) ng/g and 192 (SD) 18 ng/g) and pentachlorobenzene (298 (SD 123) ng/g and 330 (SD 35) ng/g) than all the other sites ($p < 0.01$ Bonferoni multiple range test). Mean concentrations of hexachlorobenzene in mussels placed at the two Pettit Flume sites and Occidental's sewer 003 were 373, 270 and 133 ng/g respectively. Concentrations at these sites were significantly higher than at all other station ($p < 0.01$ Bonferoni multiple range test). High concentrations of hexachlorobenzene were

Table 2. Mean (+/- Standard Deviations) Concentrations (ng/g wet weight) of Chlorinated Benzenes and Chlorinated Industrial Compounds in Mussels Introduced to the Niagara River for Three Weeks, 1989. If one or more samples were below the MDL the range was provided in place of the mean.

Sampling Station	Hexachlorobutadiene	Hexa- chlorobenzene ♦	Penta- chlorobenzene	2,3,6 - Trichlorotoluene	2,4,5 - Trichlorotoluene
MDL	1	1	1	1	1
Canadian Sites					
Fort Erie	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.
Thompsons Creek	.	.	.	.	.
NOTL	.	.	.	.	.
American Sites					
Buffalo River	.	.	.	.	.
Pettit Flume (site A)	5 +/- 4	373 +/- 156.9	298 +/- 122.7	(.) - 5	.
Pettit Flume (site B)	5 +/- 0.0	270 +/- 183.6	330 +/- 34.6	(.) - 5	.
Gratwick/ Riverside Park	.	.	.	.	.
Wheatfield	.	.	.	.	.
102nd Street	.	(.) - 30	(.) - 150	.	(.) - 15
60th St. Sewer	.	.	(.) - 3	.	.
Occidental 003	.	133 +/- 5.8	97 +/- 5.8	127 +/- 30.5	112 +/- 24.7
Gill Creek	98 +/- 66.0	(.) - 11	(.) - 2	.	.
Hyde Park	.	(.) - 2	.	.	.
Bloody Run Creek	.	37 +/- 2.9	(.) - 20	13 +/- 2.9	.

Table 2 continued

Sampling Station	1,2,3 - Trichlorobenzene	1,2,3,4 - Tetrachlorobenzene	1,2,4 - Trichlorobenzene	1,2,4,5 - Tetrachlorobenzene	1,3,5 - Trichlorobenzene
MDL	2	1	2	1	2
Canadian Sites					
Fort Erie	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.
Thompsons Creek	.	.	.	.	.
NOTL	.	.	.	.	.
American Sites					
Baffalo River	.	.	.	.	.
Pettit Flume (site A)	(.) - 80	170 +/- 69.3	50 +/- 17.3	40 +/- 52	7 +/- 2.6
Pettit Flume (site B)	112 +/- 10.4	192 +/- 17.6	70 +/- 10.0	20 +/- 0.0	(.) - 8
Gratwick/ Riverside Park	.	(.) - 2	.	.	.
Wheatfield	.	.	.	.	.

Sampling Station	1,2,3 - Trichlorobenzene	1,2,3,4 - Tetrachlorobenzene	1,2,4 - Trichlorobenzene	1,2,4,5 - Tetrachlorobenzene	1,3,5 - Trichlorobenzene
MDL	2	1	2	1	2
102nd Street	(.) - 5	(.) - 110	(.) - 1-	(.) - 10	(.) - 6
60th St. Sewer	.	4 +/- 1.1	.	.	.
Occidental 003	(.) - 15	81 +/- 13.2	(.) - 30	(.) - 5	.
Gill Creek	(.) - 7	4 +/- 1.0	15 +/- 13.2	(.) - 3	(.) - 3
Hyde Park	.	(.) - 2	.	.	.
Bloody Run Creek	.	(.) - 10	(.) - 7	.	.

"." Compound was below the method detection limit.

For all sampling sites n = 3, with the exception of 102nd Street where n = 5.

Site A = Within the contaminated inlet   Site B = Just outsite the inlet

◆ Priority Toxic Chemicals of Concern - Niagara River Toxics Management Plan

NOTL : Niagara-on-the-Lake
MDL : Method detection limit

Hexachloroethane was only detected in one mussel exposed at the Pettit Flume; 2 ng/g.

also present in two sediment samples collected from the Pettit Flume; 1,153 ng/g and 7,876 ng/g.

Pentachlorobenzene, hexachlorobenzene and 1,2,3,4-tetrachlorobenzene were all significantly higher ($p < 0.01$) in water and/or suspended sediment at Niagara-on-the-Lake than at Fort Erie in 1988/89 (Niagara River Data Interpretation Group, River Monitoring Committee 1990). The Pettit Flume is a significant source of chlorinated benzenes to the Niagara River. Hexachlorobenzene was identified as a Priority Toxic Chemicals of Concern by the NRTMP and is targeted for a 50% reduction in loadings to the Niagara River by 1996.

Gill Creek was the only site identified as a source of hexachlorobutadiene relative to the other sites that were sampled. The mean concentration of hexachlorobutadiene was 98 (SD 66) ng/g at Gill Creek where as this compound was not detected or the mean concentration was 5 ng/g at other sites (Table 2).

In general, for all chlorobenzenes and industrial compounds tested, there were no changes in concentrations in mussel tissue over-time when compared with data from 1983 and 1987, with the exception of 1,2,3,4-tetrachlorobenzene at the Pettit Flume and 102nd Street landfill site and pentachlorobenzene at the 102nd Street landfill site and Occidental's sewer 003. Mussels placed at the Pettit Flume (comparisons are between 1985, 1987 and 1989) in 1989 have lower concentrations (170 (SD 69) ng/g and 192 (SD 17) ng/g) of 1,2,3,4-tetrachlorobenzene than in 1985 (495 (SD 67) ng/g). Concentrations in 1989 are similar to concentrations in mussels in 1987 (246 (SD 60) ng/g).

Concentrations of 1,2,3,4-tetrachlorobenzene and pentachlorobenzene in mussels at 102nd Street, and pentachlorobenzene at Occidental's sewer 003, were low or not detected in 1983, they were high in 1987 (although within-site variability was high) and have now declined, although values are not as low as in 1983. In contrast to pentachlorobenzene, hexachlorbenzene concentrations in mussel tissue were higher in 1989 (133 (SD 6) ng/g) compared with 1987 values (20 (SD 8) ng/g) at the 003 sewer (concentrations are similar to 1983 values(93 (SD 79) ng/g). Chlorinated benzenes historically were stored at waste sites impacting on these sampling locations and these compounds were historically present in the effluent from the Occidental Chemical Corp. Buffalo Avenue plant (NRTC 1984).

Although not detected in mussels in 1987, 2,3,6-trichlorotoluene and 2,4,5-trichlorotoluene were present in 1989 at Occidental's sewer 003 and (only the former) at Bloody Run Creek. Mean concentrations at Occidental's sewer were 127 (SD 31) and 112 (SD 25) ng/g respectively. Low concentrations of chlorotoluene were present at these sites in 1983. Chlorotoluene was a known contaminant in Occidental's effluent (NRTC 1984). Chlorotoluenes were used in the production of pesticides, herbicides, dyes, pharmaceutical, peroxides and as solvents since the 1930s (Durham and Oliver 1983).

POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)

In general, the most frequently detected PAHs in mussel tissue were benzo(b)fluoranthene, chrysene, fluoranthene, naphthalene, phenanthrene and pyrene. With the exception of naphthalene, all these compounds are on the USEPA Priority Pollutants List, and benzo(b)fluoranthene and chrysene are considered Priority Toxic Chemicals of Concern by the NRTMP. Benzo(b)fluoranthene is targeted for the 50% reduction in loadings to the Niagara River by the NRTMP.

Some PAHs were present in the Balsam Lake mussels at trace concentrations. Acenaphthene concentrations ranged from 9 to 15 ng/g. Fluoranthene concentrations ranged from 10 to 15 ng/g, fluorene from 16 to 24 ng/g, pyrene from 8 to 11 ng/g while naphthalene and phenanthrene concentrations ranged from 39 to 58 ng/g and 34 to 60 ng/g respectively.

PAHs were present at low concentrations in the tissues of mussels exposed at Canadian sites, including the Fort Erie and Thunder Bay, Lake Erie control site (Table 3). Mussels at all of the American sites had PAHs in their tissues and in almost all cases concentrations for all compounds were higher than at Canadian sites.

Phenanthrene, naphthalene, fluorene and acenaphthene were detected for the first time in mussel tissue at all stations on the U.S side in 1989, when compared with 1987 data (with the exception of the Pettit Flume). Significantly higher concentrations ($p < 0.01$ Bonferoni multiple range test) of naphthalene were found in mussels at Occidental's sewer 003 and Hyde Park than at other sites which suggests a concentrated source of this compound, while the other stations have concentrations more representative of background levels and may be due to contamination of Balsam Lake mussels. Naphthalene was present at all Canadian sites at concentrations similar to those found in 1987 (Figure 4). These mussels may have also been influenced by background levels in the Balsam Lake mussels.

Fluorene concentrations in mussels were low (ND to 37 ng/g) and may be representative of background loadings to the U.S. side of the river (or possibly due to Balsam Lake contamination). This compound was not detected in mussels placed on the Canadian side so there is variation in the extent of the contamination of Balsam Lake mussels.

Acenaphthene concentrations in mussels were higher than fluorene at all the U.S. stations and was also detected at Niagara-on-the-Lake but concentrations were low at all sites where it was detected.

Phenanthrene concentrations in mussels at all sites were not significantly different from one another and may be due to background concentrations in the Balsam Lake mussels rather than due to site-specific contamination.

Table 3. Mean (+/- Standard Deviation) Concentrations (ng/g wet weight) of Polycyclic Aromatic Hydrocarbons in Mussels Introduced to the Niagara River for Three Weeks, 1989. If one or more samples were below the MDL the range was provided in place of the mean.

Sampling Station	Acenaphthene	Benzo(a) anthracene ♦	Benzo(a) pyrene ♦	Benzo(b) fluoranthene ♦	Chrysene ♦	Fluoranthene
MDL	8	5	8	7	6	10
Canadian Sites						
Fort Erie	.	.	.	.	10 +/- 2.1	14 +/- 3.2
Thunder Bay, Lake Erie	.	.	.	.	.	.
Frenchmans Creek	.	.	.	(.) - 10	10 +/- 1.5	.
Thompsons Creek	.	.	.	.	8	.
NOTL	(.) - 8	.	.	(.) - 9	12 +/- 2.9	(.) - 10
American Sites						
Pettit Flume (site A)	.	42 +/- 4.9	43 +/- 12.7	272 +/- 61.5	247 +/- 21.5	97 +/- 10.0
Pettit Flume (site B)	(.) - 11	68 +/- 41.7	47 +/- 22.3	315 +/- 197.5	365 +/- 178.8	193 +/- 108.5
Gratwick/ Riverside Park	.	10 +/- 2.1	.	28 +/- 3.6	23 +/- 1.1	16 +/- 1.5
Wheatfield	21 +/- 8.1	(.) - 18	.	25 +/- 14.7	37 +/- 12.7	27.7 +/- 9.5
102nd Street	(.) - 30	(.) - 6	.	(.) - 22	16 +/- 3.5	20 +/- 2.3
60th St. Sewer	.	(.) - 12	.	(.) - 36	31 +/- 10	35 +/- 8.1
Occidental 003	18 +/- 1.5	8 +/- 1	.	(.) - 60 *	100 *	33 +/- 3.1
Gill Creek	9 +/- 1.1	.	.	12 +/- 4.0	14 +/- 0.6	13 +/- 1.7
Hyde Park	23 +/- 9.87	.	.	.	.	13 +/- 2.3
Bloody Run Creek	(.) - 22	.	.	.	(.) - 5	12 +/- 3.2

Table 3 Continued

Sampling Station	Fluorene	Benzo (g,h,i) perylene	Indeno (1,2,3cd) pyrene	Naphthalene	Phenanthrene	Pyrene ♦
MDL	16	6	6	19	12	8
Canadian Sites						
Fort Erie	.	.	.	34 +/- 6.5	(.) - 18	11 +/- 1.5
Thunder Bay, Lake Erie	.	.	.	38 +/- 8.5	(.) - 16	.
Frenchmans Creek	.	.	.	(.) - 35	(.) - 46	.
Thompsons Creek	.	.	.	34	.	12
NOTL	.	.	.	38 +/- 4.1	.	(.) - 11
American Sites						
Pettit Flume (site A)	.	79 +/- 6.5 *	(.) - 70	(.) - 18	21 +/- 5.5	137 +/- 11.1
Pettit Flume (site B)	(.) - 37	(.) - 106 *	(.) - 77 *	(.) - 19	43 +/- 23.6	236 +/ 122.5
Gratwick/ Riverside Park	.	(.) - 15	(.) - 15	(.) - 19	.	17 +/- 2.5
Wheatfield	23 +/- 8.0	(.) - 10	.	90 +/- 58.0	50 +/- 12.5	32 +/- 7.0
102nd Street	(.) - 21	.	.	(.) - 144	(.) - 63	16 +/- 1.7

Sampling Station	Fluorene	Benzo (g,h,i) perylene	Indeno (1,2,3cd) pyrene	Naphthalene	Phenanthrene	Pyrene ♦
MDL	16	6	6	19	12	8
60th St. Sewer	.	(.) - 16	(.) - 14	(.) - 21	.	32 +/- 7.0
Occidental 003	(.) - 20	(.) - 7	.	89 +/- 11.0	52 +/- 5.3	37 +/- 4.6
Gill Creek	.	.	(.) - 13	23 +/- 1.5	.	11 +/- 1.0
Hyde Park	(.) - 17	.	.	104 +/- 28.4	63 +/- 20.1	(.) - 10
Bloody Run Creek	.	.	.	80 +/- 23.1	49 +/- 7.8	(.) - 10

"." Compound was below the method detection limit.

* Interpret with caution, indeterminant interference with analysis

For all sampling sites n = 3, with the exception of 102nd Street where n = 5.

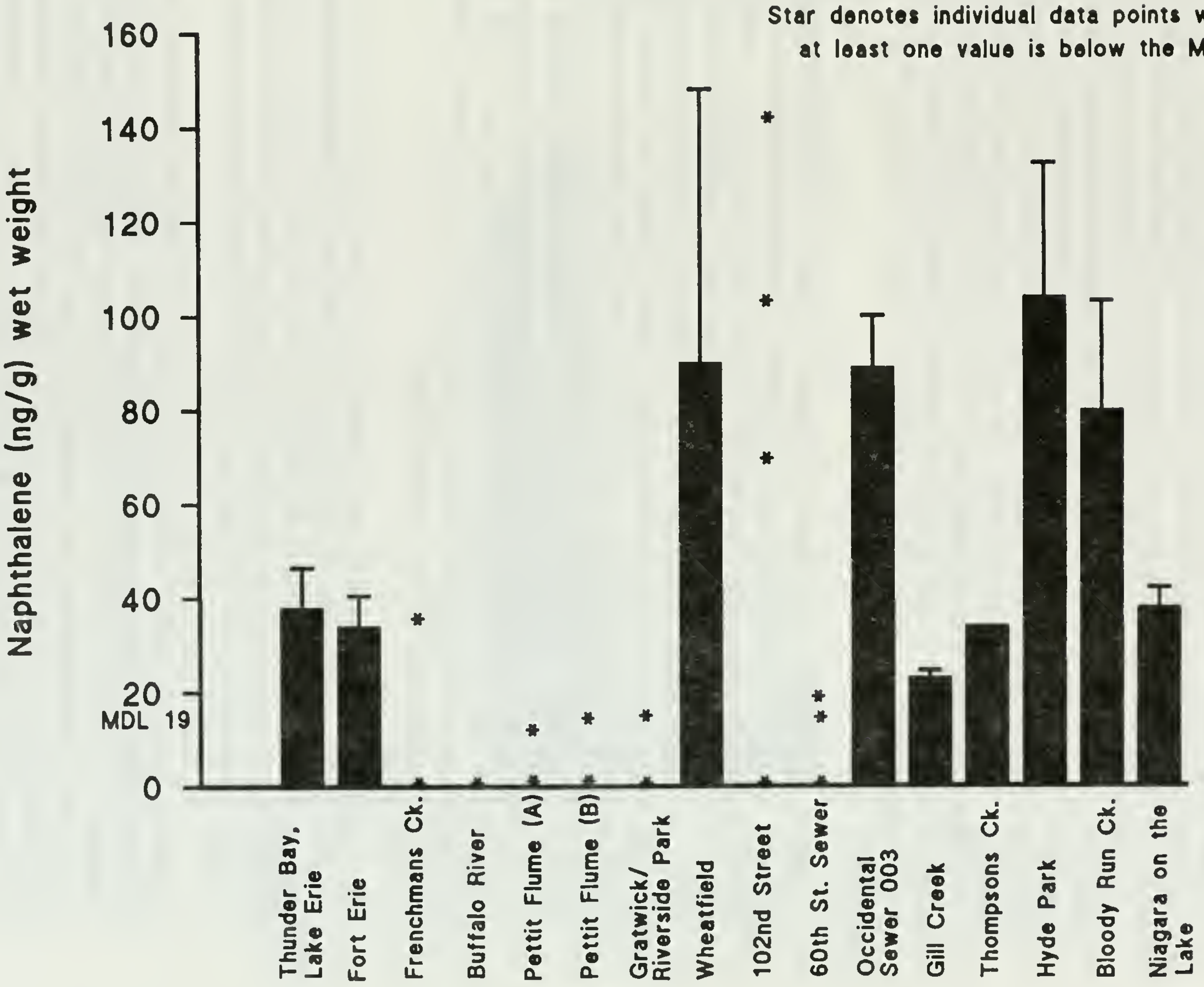
Site A = Within the contaminated Inlet Site B = Just outsite the Inlet

♦ Priority Toxic Chemicals of Concern - Niagara River Toxics Management Plan

NOTL : Niagara-on-the-Lake
MDL : Method detection limit

Acenaphthylene, Anthracene and Benzo(k)fluoranthene were not detected in any samples with the exception of the Pettit Flume which had one sample with 6 and 10 ng/g respectively. Dibenzo(a,h)anthracene was only detected in one sample at Occidental's sewer 003 at 9 ng/g.

Fig. 4: Mean Concentration of Naphthalene in Mussels, Niagara River, 1989



Star denotes individual data points when at least one value is below the MDL

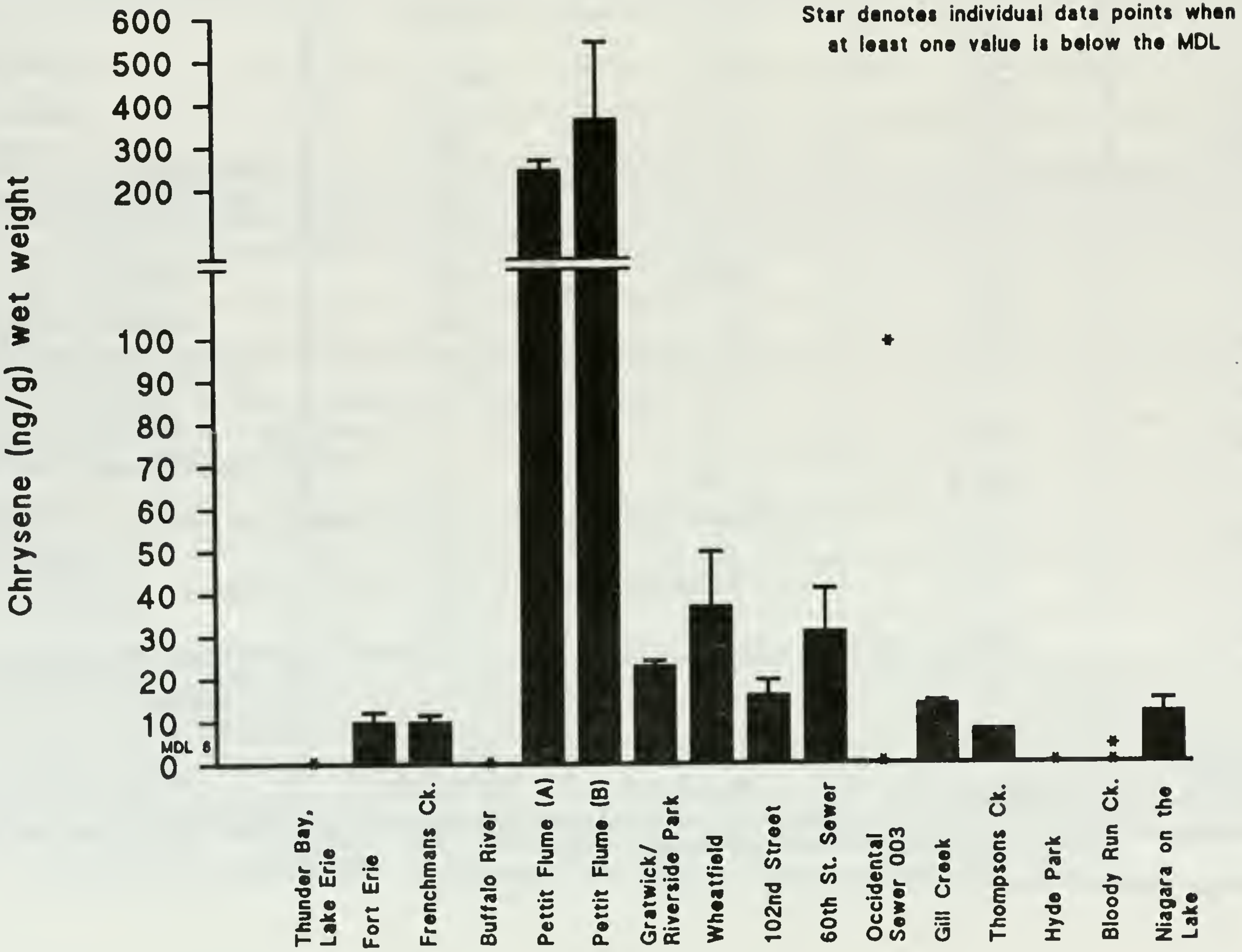
Concentrations of benzo(b)fluoranthene in mussels at Gratwick/Riverside Park (28 (SD 36) ng/g) and Gill Creek (12 (SD 4) ng/g) were significantly higher ($p < 0.01$ Bonferoni multiple range test)) than all the other sampling stations (except the Pettit Flume). Concentrations in the mussels placed at the two sites at the Pettit Flume were significantly ($p < 0.01$) higher than concentrations in mussels at all the stations tested (272 (SD 61) ng/g and 315 (SD 197) ng/g). This compound was not detected in mussels on the U.S. side in the lower Niagara but was detected at Niagara-on-the-Lake. According to the Upstream/Downstream monitoring data benzo(b)fluoranthene loadings were significantly higher at Niagara-on-the-Lake than at Fort Erie in both water and suspended sediment (Niagara River Data Interpretation Group, River Monitoring Committee 1990). Benzo(b)fluoranthene was not detected in mussels placed at Fort Erie. The mussel data suggest that the Pettit Flume, Gratwick/Riverside Park and Gill Creek are contributing to the increased loadings of benzo(b)fluoranthene in the river. This compound is of particular concern because it is a carcinogen.

Chrysene, pyrene and fluoranthene in mussels exposed at Wheatfield, Occidental's sewer 003 and the 60th Street sewer were significantly higher than concentrations in mussels placed at all other sites with the exception of the Pettit Flume where concentrations of these compounds in mussel tissues were higher than all stations sampled (Figure 5). Chrysene was found in mussels at four of the five Canadian sites (range 8 to 15 ng/g), but was not present at any of these sites in 1987. These three compounds were all significantly higher in water and suspended sediment at Niagara-on-the-Lake than at Fort Erie in 1988/89 (Niagara River Data Interpretation Group, River Monitoring Committee, 1990). The significantly higher concentrations of these PAHs in mussels at the Pettit Flume, Wheatfield, Occidental's sewer 003 and the 60th Street sewer suggest important inputs to the river. The concentrations in mussels at the other sites (range 5 to 24) are more indicative of background loadings. The presence of chrysene is of some concern since it is a mutagen and may be carcinogenic.

The Pettit Flume consistently had significantly higher concentrations of most PAH compounds in mussels than at other sites ($p < 0.01$). The high concentrations in mussels suggest that the Pettit Flume is an important point source of PAHs to the Niagara River. Of particular concern is the presence of benzo(a)pyrene which is a mutagen and is strongly carcinogenic, and the high concentrations of benzo(b)fluoranthene.

Sediment concentrations of several PAHs including benzo(b)fluoranthene, fluoranthene, chrysene, benzo(a)anthracene, benzo(k)fluoranthene, benzo(a)pyrene and pyrene have increased in sediment collected from the inlet at the Pettit Flume since 1987 (Table 4). In most cases concentrations have doubled. The variability between years may be due to the heterogeneous nature of the sediment in the inlet rather than an increase in loadings to the area (G. Kline, 1991 personal communication). The higher concentrations in the sediment in the Pettit Flume in 1989 are not reflected in mussel concentrations. Previous research (Kauss and Hamdy, 1991) with mussels as biomonitors for PAH in the St. Marys River found no significant correlation between PAHs in sediment and mussels, indicating

Fig. 5: Mean Concentration of Chrysene in Mussels, Niagara River, 1989



Star denotes individual data points when at least one value is below the MDL

Table 4. Contaminant Concentrations in Sediment (dry weight) Collected From the Pettit Flume, 102nd Street Landfill site and Thompsons Creek in 1989. Each value represents a single composite sample.

Contaminants	Pettit Flume (Site A)	Pettit Flume (Site B)	102nd Street	Thompsons Creek
Polycyclic Aromatic Hydrocarbons (ug/g)				
♣♣ Acenaphthene	0.39	0.48	0.04	0.04
Acenephthylene	0.18	0.05	0.05	0.05
Anthracene	1.1	1.6	0.01	0.02
♠♠ Benzo(a)anthracene	5.4	6.1	0.06	0.21
♠♠ Benzo(a)pyrene	6.2	5.9	0.04	0.16
♠♠ Benzo(b)fluoranthene	11.0	7.9	0.07	0.38
Benzo(g,h,i)perylene	1.10	1.10	0.04	0.09
Benzo(k)fluoranthene	3.6	3.4	0.04	0.08
♠♠ Dibenzo(a,h)anthracene	0.25	0.47	0.04	0.04
♦♦ Indeno(1,2,3-cd)pyrene	1.8	1.3	0.04	0.12
♠♠ Chrysene	8.5	8.1	0.04	0.20
Naphthalene	* 0.37	* 0.13	0.04	0.04
Pyrene	12.0	12.0	0.09	0.28
Phenanthrene	5.8	8.10	0.07	0.15
Fluoranthene	14.0	15.0	0.12	0.36
Fluorene	0.64	0.79	0.04	0.04

Contaminants	Pettit Flume (Site A)	Pettit Flume (Site B)	102nd Street	Thompsons Creek
Organochlorine Pesticides (ng/g)				
α-Chlordane	11	.	.	.
γ-Chlordane	20	.	.	.
Total PCBs	615	.	.	285
Chlorinated Benzenes (ng/g)				
Hexachlorobenzene	1153	7876	3	.
Pentachlorobenzene	16	.	.	.

♠♠ = This compound is both carcinogenic and mutagenic
♦♦ = This compound is carcinogenic
♣♣ = This compound is mutagenic

* = Results Determined on Diluted Sample "." = Not Detected

Site A = Within the contaminated inlet Site B = Just outsite the inlet

All other contaminants analysed for were not detected in any of the samples collected.

that for mussels (which are filter feeding organisms) exposure is primarily via water and, therefore, due to ongoing inputs. The PAHs found in the sediment at the other two sites (102nd Street and Thompsons Creek) (Table 4) did not reflect contaminant concentrations in mussels either. Muncaster *et al.* (1989) did not find a significant difference in tissue concentrations of organic compounds in mussels placed on the sediment or in the water column and suggested that the sediment did not play an important role in contaminant uptake. Similarly Pugsley *et al.* (1985) found that mussel body burdens of organics were only weakly correlated with concentrations in the sediment.

Concentrations of most PAHs in mussel tissue in 1989 were consistent with results from 1987, with the exception of Occidental's sewer 003, Bloody Run Creek, Gill Creek and Niagara-on-the-Lake. Concentrations of fluoranthene, pyrene, benzo(a)anthracene and benzo(b)fluoranthene were all lower in 1989 at Occidental's sewer than in 1987. The opposite trend was found at the other three sites. In 1987, PAHs were not detected in mussels from Bloody Run Creek (with the exception of chrysene) and Gill Creek, while in 1989 several compounds (acenaphthene, benzo(b)fluoranthene, chrysene, naphthalene, fluoranthene and pyrene) were present at low concentrations. Interestingly, these compounds are the same ones (and at similar concentrations), that were present in mussels at Niagara-on-the-Lake in 1989 (PAHs were not detected at that site either in 1987). Only two of these compounds, benzo(b)fluoranthene and chrysene were not present in Balsam Lake mussels which may be an explanation as to why the other four compounds were detected in the mussels at these three sites. Detection of benzo(b)fluoranthene and chrysene, however, may indicate an increased input in the Niagara Falls area and the lower Niagara River.

INORGANIC CONTAMINANTS

Inorganic Contaminants in Mussels

Mussel tissues were analysed for arsenic, cadmium, copper, mercury, manganese, nickel, lead, selenium and zinc. In most cases concentrations in caged mussels (from all sites) were not significantly different than the Balsam Lake mussels and the control mussels introduced at Thunder Bay, Lake Erie. The exceptions were for copper, mercury and nickel (Table 5).

Concentrations of copper were significantly higher ($p < 0.0001$ Tukeys significant difference test) in mussels exposed at the Pettit Flume and Gill Creek than at all other stations. The high concentrations of copper in mussels at Gill Creek may be due to leaching from a waste site owned by E.I. Dupont de Nemours & Co. Inc. located immediately west of Gill Creek. Copper sludge from copper and zinc cyanide processes were historically stored in drums at this site (Interagency Task Force on Hazardous Waste 1979). Copper was also significantly higher in mussels placed at Occidental's sewer 003 than the mussels at the control site but was not significantly different from the other sites.

Table 5. Mean (+/- Standard Deviation) Concentrations (μg/g wet weight) of Inorganic Contaminants in Mussels Exposed to the Niagara River for Three Weeks, 1989.

	◆ Arsenic	Cadmium	Copper	◆ Mercury	Manganese
Sampling Station					
Balsam Lake (control)	0.54 +/- 0.13	0.82 +/- 0.41	1.17 +/- 0.06	0.03 +/- 0.00	616.67 +/- 166.23
Fort Erie	0.54 +/- 0.32	0.84 +/- 0.12	1.43 +/- 0.06	0.01 +/- 0.01	573.33 +/- 717.03
Thunder Bay, Lake Erie	0.53 +/- 0.07	0.71 +/- 0.04	1.01 +/- 0.29	0.02 +/- 0.01	826.67 +/- 166.23
Frenchmans Creek	0.37 +/- 0.11	0.89 +/- 0.13	1.73 +/- 0.21	0.01 +/- 0.01	706.67 +/- 485.21
Thompsons Creek	0.32 +/- 0.06	0.83 +/- 0.41	1.17 +/- 0.12	0.02 +/- 0.01	790.00 +/- 167.03
NOTL	0.45 +/- 0.13	0.57 +/- 0.15	1.53 +/- 0.06	0.02 +/- 0.01	810.00 +/- 174.36
Buffalo River	0.83 +/- 0.59	0.63 +/- 0.24	2.13 +/- 0.25	0.03 +/- 0.02	370.00 +/- 90.00
Pettit Flume (Site A)	0.50 +/- 0.08	0.72 +/- 0.12	6.67 +/- 3.80	0.05 +/- 0.03	740.00 +/- 450.33
Pettit Flume (Site B)	0.37 +/- 0.11	0.61 +/- 0.22	4.60 +/- 1.48	0.03 +/- 0.01	26.67 +/- 170.39
Gratwick/Riverside Park	0.31 +/- 0.05	0.80 +/- 0.05	1.70 +/- 0.46	0.02 +/- 0.01	743.33 +/- 228.55
Wheatfield	0.47 +/- 0.15	0.63 +/- 0.12	1.63 +/- 0.31	0.05 +/- 0.07	336.67 +/- 57.74
102nd Street	0.34 +/- 0.23	0.65 +/- 0.18	1.29 +/- 0.37	0.10 +/- 0.03	732.00 +/- 569.67
60th Street Sewer	0.56 +/- 0.16	0.75 +/- 0.11	1.37 +/- 0.46	0.04 +/- 0.01	866.67 +/- 41.63
Occidental 003	0.34 +/- 0.27	0.70 +/- 0.36	2.40 +/- 0.17	0.03 +/- 0.01	1053.33 +/- 127.41
Gill Creek	0.46 +/- 0.18	0.96 +/- 0.22	4.17 +/- 0.83	0.03 +/- 0.01	130.33 +/- 69.50
Hyde Park	0.09 +/- 0.04	1.03 +/- 0.06	1.30 +/- 0.17	0.02 +/- 0.02	1003.33 +/- 749.69
Bloody Run Creek	0.62 +/- 0.32	0.77 +/- 0.26	1.47 +/- 0.06	0.02 +/- 0.02	1300.00 +/- 264.58

Table 5 continued.

	Nickel	Lead	Selenium	Zinc
Sampling Station				
Balsam Lake (Control)	0.40 +/- 0.00	0.60	0.51 +/- 0.07	31.67 +/- 2.08
Fort Erie	0.43 +/- 0.06	0.60 +/- 0.10	0.64 +/- 0.31	40.67 +/- 12.50
Thunder Bay, Lake Erie	0.47 +/- 0.06	0.67 +/- 0.06	0.60 +/- 0.16	33.67 +/- 1.53
Frenchmans Creek	0.47 +/- 0.06	0.67 +/- 0.06	0.43 +/- 0.14	34.00 +/- 8.66
Thompsons Creek	0.47 +/- 0.06	0.63 +/- 0.12	0.35 +/- 0.04	34.67 +/- 8.33
NOTL	0.43 +/- 0.06	0.63 +/- 0.06	0.55 +/- 0.30	37.33 +/- 7.51
Buffalo River	0.48 +/- 0.07	0.63 +/- 0.12	0.55 +/- 0.32	41.00 +/- 20.52
Pettit Flume (Site A)	0.43 +/- 0.06	0.63 +/- 0.06	0.50 +/- 0.03	70.33 +/- 13.01
Pettit Flume (Site B)	0.40	0.60	0.41 +/- 0.03	42.33 +/- 8.74
Gratwick/Riverside Park	0.47 +/- 0.06	0.63 +/- 0.06	0.36 +/- 0.02	37.00 +/- 8.00
Wheatfield	0.47 +/- 0.06	0.70 +/- 0.10	0.47 +/- 0.06	56.00 +/- 6.24
102nd Street	0.42 +/- 0.05	0.60 +/- 0.07	0.40 +/- 0.06	43.60 +/- 13.39
60th Street Sewer	0.40	0.60	0.59 +/- 0.44	43.67 +/- 7.57
Occidental 003	0.49 +/- 0.12	0.63 +/- 0.06	0.30 +/- 0.02	45.67 +/- 11.59
Gill Creek	0.66 +/- 0.11	0.63 +/- 0.06	0.36 +/- 0.03	40.67 +/- 12.86
Hyde Park	0.50	0.70	0.33 +/- 0.10	45.33 +/- 4.73
Bloody Run Creek	0.50	0.70	0.57 +/- 0.37	33.67 +/- 5.69

For all sampling sites n = 3, with the exception of 102nd Street where n = 5.

Site A = Within the contaminated inlet Site B = Just outsite the inlet

♦ Priority Toxic Chemicals of Concern - Niagara River Toxics Management Plan.

NOTL : Niagara-on-the-Lake

Mussels exposed at Gill Creek also had significantly ($p<0.001$) higher concentrations of nickel than at the Thunder Bay, Lake Erie control, and when compared with concentrations in mussels at most stations (the exception being Bloody Run Creek, Hyde Park, Occidental's sewer 003 and Buffalo River).

Mercury concentrations were highest in mussels exposed at the 102nd Street landfill site ($p<0.0004$) when compared to concentrations found in mussels exposed at all other sites. The only exception was at the outer Pettit Flume station and Wheatfield. Concentrations of mercury in mussels at these sites , however, were not significantly different than mercury concentrations in mussels at all other sites. The 102nd Street landfill site was partly owned by the Olin Corporation. An estimated 20,000 tons of brine sludge with mercury was deposited there between 1948 and 1970 (Interagency Task Force on Hazardous Waste 1979). It is not surprising to find mercury contamination associated with this site. Mercury has been identified at a Priority Toxic Chemical of Concern by the NRTMP and is targeted for a 50% loading reduction to the Niagara River.

Based on these results the use of caged mussels as biomonitors for metal pollution in short term exposures studies may be limited. Other studies have shown considerable variability in mussel contaminant concentrations in general for metals (Tessier *et al.* 1984; Lobel *et al.* 1989; Lobel *et al.* 1991) and specifically for transplant experiments. Hinch and Green (1989), found that metal concentrations in transplanted mussels tended to reflect the metal concentrations of their source environment for up to a year post-transplant. They found a strong influence of the source environment on the growth and metal uptake by the mussels indicating that short exposure periods may not be sufficient to measure contaminant loadings in the destination environment.

Inorganic Contaminants in Sediment

Sediment samples were only collected from the Pettit Flume, 102nd Street landfill site and Thompsons Creek (Table 6). Metal concentrations in the sediment did not reflect concentrations of inorganic contaminants found in mussels in most cases, although there were a few exceptions. The Pettit Flume had high concentrations of copper in mussels and copper concentrations in the sediment at the Pettit Flume exceeded the Provincial Sediment Quality Guidelines' "severe effect level" designated as the concentration of a compound that is expected to be detrimental to benthic organisms (Persaud *et al.* 1992). The "severe effect level" was also exceeded for mercury at the 102nd Street landfill site where mussels also had higher concentrations of mercury than at all other sites. In general, however, due to the small number of sites sampled it is impossible to make any conclusions about the relationship between sediment concentrations of inorganic compounds and mussel tissue concentrations. The high concentrations of these metals in the sediment just confirm their presence at those sites.

Table 6. Concentration of Metals (dry weight) in Composite Sediment Samples Collected From Selected Sites in the Niagara River, 1989.

	Stations			
	102nd Street Landfill Site	Pettit Flume (Site A)	Pettit Flume (Site B)	Thompsons Creek
Metals (µg/g)				
Aluminum	3400	11000	5400	24000
Arsenic	1.3	5.5 ♦	3.4	5.3 ♦
Barium	35	120	71	120
Cadmium	0.4	2.3 ♦	1.4 ♦	0.32
Chromium	35 ♦	69 ♦	62 ♦	100 ♠
Copper	11	450 ♠	270 ♠	52 ♠
Iron (%)	0.7	2.3 ♦	1.4	3 ♦
Mercury	2.5 ♠	8.2 ♠	1.6 ♠	0.54 ♦
Manganese	96	340	290	480 ♦
Nickel	22 ♦	42 ♦	21 ♦	130 ♠
Lead	18	230 ♦	250 ♠	69 ♦
Selenium	0.2	1.6	0.48	0.68
Zinc	69	610 ♦	360 ♦	150 ♦

♦ Concentration of the compound exceeds the draft Provincial Sediment Quality Guideline "lowest effect level".

♠ Concentration of the compound exceeds the draft Provincial Sediment Quality Guideline "sever effect level".

Although it was not reflected in the mussel tissue concentrations, "Severe effect levels" were also exceeded for mercury, nickel and lead (and approached for zinc) at the Pettit Flume, and for nickel at the 102nd Street landfill. Thompsons Creek exceeded the "severe effect level" for chromium and the "lowest effect level" for copper, mercury, manganese, nickel, lead and zinc. Thompson's Creek receives cooling and process effluent from Cyanamid of Canada, Welland Plant. Based on data in the 1980s the facility was identified as a significant contributor of toxics in the Ontario portion of the Niagara River drainage basin by the NRTC review. Metals were the major sources of toxics cited at the time. The major source of metals has been eliminated with the discontinuation of chrome in the cooling water in 1990 (Niagara River Remedial Action Plan, Stage 1 1992).

POLYCHLORINATED DIBENZO-P-DIOXINS AND FURANS IN SEDIMENT

A range of polychlorinated dioxins and furans including the most toxic form of dioxin, 2,3,7,8-TCDD (tetrachlorodibenzo-p-dioxin) was detected in the sediment collected from the Pettit Flume (Table 7). Concentrations of 2,3,7,8-TCDD were 0.520 and 1.100 ng/g at the two sites sampled. These values are lower than in the 1987 study, which found 9 ng/g as 2,3,7,8-TCDD in the sediment. Concentrations of all the dioxins and furans tested were lower in 1989 than in 1987 and in many cases are at least ten times lower than 1987 values. Nevertheless, the concentrations are still high compared to other sites tested in the Niagara river and are still considered an environmental concern. As with the PAH analysis, it is not known if the variability between years is due to the heterogeneous nature of the sediment in the inlet rather than any real decline in loadings to the area. In 1979, Occidental Chemical Corp. chemists confirmed that TCDD was a byproduct of their plant process and that it was present in the phenol tar waste. Subsequent sampling found TCDD in soil surrounding the facility and waste sites and in one sewer sample indicating that this was a source of dioxins to the Pettit Flume (Geologic Testing Consultants 1984).

Chlorinated dioxins and furans were also detected in surficial sediment collected near the 102nd Street landfill site. Concentrations in 1987 were about ten times higher than they were in 1989. Concentrations in sediment in 1989 were at least 100 times higher at the Pettit Flume and in some cases 1000 times higher than contaminant levels found in sediment collected from the 102nd Street site.

Table 7. Concentrations (ng/g dry weight) of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans in a single composite sediment sample collected from the Pettit Flume and 102nd Street Landfill Site.

Contaminants	Pettit Flume		102nd Street
	Site A	Site B	
Dioxins			
2,3,7,8 TCDD ♦	0.520	1.100	
T4CDD	16	46	.
P5CDD	24	72	.
H6CDD	57	150	.
H7CDD	33	95	0.220
O8CDD	0.075	21**	0.750
Furans			
T4CDF	190	320	.
P5CDF	190	400	0.023
H6CDF	320	440	0.056
H7CDF	240	630	0.110
O8CDF	1.2	190**	0.059

Values are corrected for recovery of isotopically labelled surrogate standards.
** Values not corrected due to low recovery of surrogate standard.

" ." Compound was below the Method Detection Limit

Site A = Within the contaminated inlet   Site B = Just outsite the inlet

♦ Priority Toxic Chemicals of Concern - Niagara River Toxics Management Plan.

CHLORINATED PHENOLS IN LEECHES

Leeches were chosen as biomonitors since previous research has shown that they are effective accumulators of chlorinated phenols, particularly when compared with mussels (Metcalfe and Hayton 1989). Leeches were deployed in cages at five sites where we suspected that there was a source of chlorinated phenols based on previous surveys and known industrial discharges. Three replicate samples of leeches were submitted for analysis to test for background concentrations of chlorinated phenols. In all case chlorinated phenols were not detected.

Pentachlorophenol and 2,4,6 trichlorophenol were detected in leeches collected from the manhole of the Canadian Oxy-Chemical facility in Fort Erie (Frenchmans Creek) (Table 8). The non-contact cooling water from the plant operations passes through this man-hole and flows into Frenchmans Creek. Concentrations in the tissues were low and highly variable but indicate the presence of these compounds in the effluent, their bioavailability and movement to Frenchmans Creek. These same compounds were the only ones present in the leeches in 1987 and concentrations were consistent between the two surveys.

Four of the six chlorophenolic compounds tested for were also detected in leeches at the Pettit Flume (Table 8). Contaminant concentrations within the Pettit Flume sites were also variable. Contaminant levels in leech tissues were consistent in 1989 with values in 1987 with the exception of 2,4,6-trichlorophenol which was high in two samples analysed in 1987: 1,715 ng/g and 4,080 ng/g (not detected in the third sample), but was not detected in any samples in 1989. 2,4,6-trichlorophenol was detected in one of the sediment samples collected from the Pettit Flume (78 ng/g) in 1989. Pentachlorophenol, 2,3,4-trichlorophenol and 2,4,5-trichlorophenol were also detected in the sediment (Table 9).

Both the Canadian Oxy-Chemical facility and Occidental Chemical Corporation, Durez Division in North Tonawanda produce phenolic resins and various moulding compounds and plastics which contain phenols (NRTC 1984). It is not surprising to find chlorinated phenolic compounds associated with these sites.

Chlorinated phenols were not detected in leeches exposed at Gratwick/Riverside Park in 1989, while 2,4,5-trichlorophenol, 2,4,6-trichlorophenol and pentachlorophenol were detected in 1987. Chlorinated phenols were landfilled at that site between 1962 and 1968 (Raven, 1991). Similarly, chlorinated phenols were not detected in leeches at Niagara-on-the-Lake in 1987 or in 1989; however, 2,4,5-trichlorophenol and 2,4,6-trichlorophenol were both detected at higher concentrations in water at Niagara-on-the-Lake when compared with water collected at Fort Erie in 1988/89 (Niagara River Data Interpretation Group, River Monitoring Committee 1990).

Table 8. Concentrations (ng/g wet weight) of Chlorinated Phenols in Leeches Introduced to the Niagara River for Three Weeks, 1989. Three replicate samples were collected at each station.

Sampling Station	Pentachlorophenol	2,3,4 - Trichlorophenol	2,3,4,5 - Tetrachlorophenol	2,3,5,6 - Tetrachlorophenol	2,4,5 - Trichlorophenol	2,4,6 - Trichlorophenol
MDL	50	100	50	50	50	50
Canadian Sites						
NOTL	.	.	.	.	.	.
NOTL	.	.	.	.	.	.
NOTL	.	.	.	.	.	.
Frenchmans Creek	60	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.	150
Frenchmans Creek	.	.	.	.	.	100
American Sites						
Pettit Flume (site A)	.	.	.	.	.	.
Pettit Flume (site A)	.	.	.	.	.	.
Pettit Flume (site A)	.	.	.	70	70	.
Pettit Flume (site B)	.	.	.	.	.	.
Pettit Flume (site B)	130	180	.	150	130	.
Pettit Flume (site B)	.	.	.	.	.	.
Gratwick/ Riverside Park	.	.	.	.	.	.

NOTL : Niagara-on-the-Lake
MDL : Method detection limit

"." Compound was below the method detection limit.

Site A = Within the contaminated inlet   Site B = Just outsite the inlet

Table 9. Concentrations of Chlorinated Phenols in Sediment (dry weight) Collected From the Pettit Flume, 102nd Street Landfill site and Thompsons Creek in 1989. Each value represents a single composite sample.

Contaminants	Pettit Flume (Site A)	Pettit Flume (Site B)	102nd Street	Thompsons Creek
Chlorinated Phenols (ng/g)				
Pentachlorophenol	.	115	.	.
2,3,4-Trichlorophenol	162	137	.	.
2,4,6-Trichlorophenol	78	.	.	.

"." = Not Detected

Site A = Within the contaminated inlet   Site B = Just outsite the inlet

All other contaminants analysed for were not detected in any of the samples collected.

CONCLUSIONS and RECOMMENDATIONS

The use of biomonitors to identify the presence and sources of contaminants in the Niagara River is an important component of the Niagara River Toxics Management Plan. Frequently, contaminants are present in the water column below the limits of detection by the analytical laboratories; however, their presence may have an impact on the biota and on community structure.

A comparison of contaminant concentrations in mussels and leeches placed within the Niagara river with concentrations in biomonitors placed at Thunder Bay, Lake Erie, confirm that the origin of many of the contaminants entering Lake Ontario is not Lake Erie but rather point and non-point sources located along the river. The data for mussels and leeches show that the majority of contaminants detected were found on the U.S. side of the river at the Pettit Flume in North Tonawanda, the 102nd Street landfill site, Occidental's Buffalo Avenue plant (sewer 003), and the mouths of Gill Creek and Bloody Run Creek. In almost all cases, with the exception of polycyclic aromatic hydrocarbons, contaminants were not present in mussels introduced to the Canadian side of the Niagara River and at the Thunder Bay, Lake Erie control site. The data suggest contaminant input from the U. S. sites rather than from Lake Erie. The biomonitoring data confirm results from studies using other media (sediment, water, suspended sediment and biota) which have shown that Lake Erie was not the source of many of the contaminants detected in the Niagara River (Kuntz and Warry 1983; Kauss 1983; Whittle and Fitzsimons 1983; Niagara River Data Interpretation Group, River Monitoring Committee 1990). The data from this study and other studies show that the Niagara River is clearly an important source of contaminants to Lake Ontario and subsequently the St. Lawrence River.

Mussels and leeches were useful biomonitors of organic contaminants and chlorinated phenols respectively; however, the effectiveness of mussels as monitors of inorganic contaminants requires further research. With only a few exceptions, concentrations of metals in mussels placed in the river for three weeks were not significantly different than the mussels initially analyzed from Balsam Lake suggesting that they may not have been present in the water for a sufficient amount of time.

Future biomonitoring surveys should attempt to identify the sources of variability in contaminant concentrations between individual mussels and develop alternate study designs to reduce this variability.

This study effectively identifies sources of contamination and will be particularly useful in the future to assess the success of waste site remediation in terms of containment of contaminants and elimination of contaminant leaching to the river. There should be a long term commitment to continue the biomonitoring program in the Niagara River.

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APPENDIX 1

ANALYTICAL TESTS

Table A.1 List of compounds for mussel and leech analysis.

Industrial Compounds/ Chlorinated Benzenes	**Organochlorine Pesticides/ Total PCBs**
Mussel Tissue Analysis	
Hexachlorobutadiene	Total PCBs
2,3,6 Trichlorotoluene	Heptachlor
2,6,a Trichlorotoluene	Aldrin
2,4,5 Trichlorotoluene	Toxaphene
1,2,4 Trichlorobenzene	Mirex
1,3,5 Trichlorobenzene	α-BHC
1,2,3 Trichlorobenzene	β-BHC
1,2,3,4 Tetrachlorobenzene	γ-BHC
1,2,3,5 Tetrachlorobenzene	α-Chlordane
1,2,4,5 Tetrachlorobenzene	γ-Chlordane
Pentachlorobenzene	o,p'-DDT
Hexachlorobenzene	p,p'-DDD
Octachlorostyrene	p,p'-DDT
Hexachloroethane	p,p'-DDE
PAHs (See Table 3 for complete list)	See Table 7 for list of dioxins/furans
	Polychlorinated dibenzo furans
Lipid(%)	Polychlorinated dibenzo-p-dioxins
Leech Tissue Analyses:	
2,3,4 Trichlorophenol	Lipids (%)
2,4,5 Trichlorophenol	
2,4,6 Trichlorophenol	
2,3,4,5 Tetrachlorophenol	
2,3,5,6 Tetrachlorophenol	
Pentachlorophenol	

APPENDIX 2

RAW DATA FILES.

Table A2. Concentrations (ng/g) of Organochlorine Pesticides and PCBs in Mussels Introduced to the Niagara River for Three Weeks, 1989.

Sampling Station	α BHC	β BHC	δ BHC	α Chlordane	γ Chlordane	Mirex	Octa-chlorostyrene	p'p'-DDD	p'p'-DDE	p'p'-DDT	Total PCB	% Lipid
MDL	1	1	1	2	2	5	1	5	1	5	20	
Canadian Sites												
Fort Erie	.	.	.	.	.	.	.	.	.	.	.	1.20
Fort Erie	.	.	.	.	.	.	.	.	.	.	.	0.87
Fort Erie	.	.	.	.	.	.	.	.	.	.	.	1.03
Thunder Bay, Lake Erie	.	.	.	.	.	.	.	.	.	.	.	1.20
Thunder Bay, Lake Erie	.	.	.	.	.	.	.	.	.	.	.	0.89
Thunder Bay, Lake Erie	.	.	.	.	.	.	.	.	.	.	.	1.20
Frenchmans Creek	.	.	.	.	.	.	.	.	.	.	.	1.30
Frenchmans Creek	.	.	.	.	.	.	.	.	.	.	.	1.01
Frenchmans Creek	.	.	.	.	.	.	.	.	.	.	.	1.30
Thompsons Creek	.	.	.	.	.	.	.	.	.	.	.	0.77
Thompsons Creek	.	.	.	.	.	.	.	.	2	.	.	1.60
Thompsons Creek	.	.	.	.	.	.	.	.	.	.	.	0.92
NOTL	.	.	.	.	.	.	.	.	.	.	.	0.63
NOTL	.	.	.	.	.	.	.	.	2	.	.	0.94
NOTL	.	.	.	.	.	.	.	.	.	.	.	1.10
American Sites												
Buffalo River	.	.	.	.	.	.	.	13	.	.	.	1.43
Buffalo River	.	.	.	.	.	.	.	6	.	.	.	0.80
Buffalo River	.	.	.	.	.	.	.	7	.	.	60	0.84

Sampling Station	α BHC	β BHC	δ BHC	α Chlordane	γ Chlordane	Mirex	Octa-chlorostyrene	p'p'-DDD	p'p'-DDE	p'p'-DDT	Total PCB	% Lipid
MDL	1	1	1	2	2	5	1	5	1	5	20	
Pettit Flume (site A)	.	.	.	.	.	.	8	.	2	.	70	1.40
Pettit Flume (site A)	4	.	.	4	7	.	5	.	.	.	40	1.50
Pettit Flume (site A)	2	.	.	.	4	.	5	.	.	.	70	0.80
Pettit Flume (site B)	2	.	2	5	6	.	5	.	.	8	90	1.00
Pettit Flume (site B)	4	.	.	5	7	.	5	.	.	.	80	1.60
Pettit Flume (site B)	2	.	.	4	4	.	5	.	.	.	100	0.95
Gratwick/Riverside Park	.	.	.	.	.	.	.	.	.	.	.	1.50
Gratwick/Riverside Park	.	.	.	.	.	.	.	.	.	.	.	1.10
Gratwick/Riverside Park	.	.	.	.	.	.	.	.	.	.	.	1.00
Wheatfield	.	.	.	.	.	.	.	.	.	.	.	0.65
Wheatfield	.	.	.	.	.	.	.	.	.	.	.	0.29
Wheatfield	.	.	.	.	.	.	.	.	.	.	.	1.20
102nd Street	15	5	3	.	.	.	.	.	.	.	100	0.70
102nd Street	10	.	.	.	.	.	.	.	.	.	60	1.20
102nd Street	15	4	.	.	5	45	.	.	27	.	400	0.60
102nd Street	17	4	.	.	.	.	2	.	6	.	.	0.33
102nd Street	17	.	.	.	.	.	.	.	7	.	.	0.54
60th St. Sewer	3	.	.	.	.	.	.	.	8	.	60	1.60
60th St. Sewer	3	.	.	.	.	.	.	.	.	.	.	1.40
60th St. Sewer	3	.	2	.	.	.	.	.	.	.	500	1.70

Sampling Station	α BHC	β BHC	δ BHC	α Chlordane	γ Chlordane	Mirex	Octa-chlorostyrene	p'p'-DDD	p'p'-DDE	p'p'-DDT	Total PCB	% Lipid
MDL	1	1	1	2	2	5	1	5	1	5	20	
Occidental 003	5	3	2	7	25	.	15	7	4	13	80	0.20
Occidental 003	11	7	.	.	19	40	15	8	8	12	250	0.50
Occidental 003	2	3	.	5	50	.	20	8	.	12	60	0.13
Gill Creek	9	3	.	.	.	.	25	.	.	.	.	0.86
Gill Creek	120	20	.	.	.	.	32	.	.	.	650	1.50
Gill Creek	12	10	.	.	.	.	13	.	.	.	200	1.00
Hyde Park	.	.	.	.	.	.	4	.	.	.	.	0.10
Hyde Park	.	.	.	.	.	.	3	.	2	.	.	0.30
Hyde Park	.	.	.	.	.	.	.	.	.	.	.	0.10
Bloody Run Creek	4	.	.	.	.	.	.	.	2	.	.	0.20
Bloody Run Creek	2	.	.	.	.	50	10	.	6	.	200	0.20
Bloody Run Creek	2	.	.	.	.	50	2	.	13	.	220	0.15

NOTL : Niagara-on-the-Lake
MDL : Method detection limit

"." Compound was below the method detection limit.

Aldrin, Heptachlor and o'p'-DDT were not detected in any samples analysed.

Table A3. Concentrations (ng/g) of Chlorinated Benzenes and Industrial Chlorinated Compounds in Mussels Introduced to the Niagara River for Three Weeks, 1989.

Sampling Station	Hexachlorobutadiene	Hexachlorobenzene	Hexachloroethane	Pentachlorobenzene	2,3,6 - Trichlorotoluene	2,4,5 - Trichlorotoluene
MDL	1	1	1	1	1	1
Canadian Sites						
Fort Erie	.	.	.	.	.	.
Fort Erie	.	.	.	.	.	.
Fort Erie	.	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.	.
Thompsons Creek	.	.	.	.	.	.
Thompsons Creek	.	.	.	.	.	.
Thompsons Creek	.	.	.	.	.	.
NOTL	.	.	.	.	.	.
NOTL	.	.	.	.	.	.

Sampling Station	Hexachlorobutadiene	Hexachlorobenzene	Hexachloroethane	Pentachlorobenzene	2,3,6 - Trichlorotoluene	2,4,5 - Trichlorotoluene
MDL	1	1	1	1	1	1
NOTL	.	.	.	.	.	.
American Sites						
Buffalo River	.	.	.	.	.	.
Buffalo River	.	.	.	.	.	.
Buffalo River	.	.	.	.	.	.
Pettit Flume (site A)	10	550	.	440	3	.
Pettit Flume (site A)	3	320	.	225	.	.
Pettit Flume (site A)	3	250	.	230	5	.
Pettit Flume (site B)	5	350	.	370	5	.
Pettit Flume (site B)	5	400	.	310	.	.
Pettit Flume (site B)	5	60	.	310	.	.

Sampling Station	Hexachlorobutadiene	Hexachlorobenzene	Hexachloroethane	Pentachlorobenzene	2,3,6 - Trichlorotoluene	2,4,5 - Trichlorotoluene
MDL	1	1	1	1	1	1
Gratwick/ Riverside Park	.	.	.	.	.	.
Gratwick/ Riverside Park	.	.	.	.	.	.
Gratwick/ Riverside Park	.	.	.	.	.	.
Wheatfield	.	.	.	.	.	.
Wheatfield	.	.	.	.	.	.
Wheatfield	.	.	.	.	.	.
102nd Street	.	15	.	150	.	15
102nd Street	.	12	.	110	.	.
102nd Street	.	.	.	.	.	.
102nd Street	.	30	.	110	.	.
102nd Street	.	15	.	70	.	.
60th St. Sewer	.	.	.	3	.	.
60th St. Sewer	.	.	.	2	.	.
60th St. Sewer	.	.	.	.	.	.
Occidental 003	.	130	.	100	120	100
Occidental 003	.	140	.	100	100	95
Occidental 003	.	130	.	90	160	140

Sampling Station	Hexachlorobutadiene	Hexachlorobenzene	Hexachloroethane	Pentachlorobenzene	2,3,6 - Trichlorotoluene	2,4,5 - Trichlorotoluene
MDL	1	1	1	1	1	1
Gill Creek	40	11	.	.	.	.
Gill Creek	85	10	2	.	.	.
Gill Creek	170	.	.	2	.	.
Hyde Park	.	.	.	.	.	.
Hyde Park	.	2	.	.	.	.
Hyde Park	.	.	.	.	.	.
Bloody Run Creek	.	35	.	7	10	.
Bloody Run Creek	.	35	.	.	15	.
Bloody Run Creek	.	40	.	20	15	.

NOTL : Niagara-on-the-Lake
MDL : Method detection limit

"." Compound was below the method detection limit.

Table A3 continued.

Sampling Station	1,2,3 - Trichlorobenzene	1,2,3,4 - Tetrachlorobenzene	1,2,4 - Trichlorobenzene	1,2,4,5 - Tetrachlorobenzene	1,3,5 - Trichlorobenzene
MDL	2	1	2	1	2
Canadian Sites					
Fort Erie	.	.	.	.	.
Fort Erie	.	.	.	.	.
Fort Erie	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.
Thunder Bay, Lake Erie	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.
Frenchmans Creek	.	.	.	.	.
Thompsons Creek	.	.	.	.	.
Thompsons Creek	.	.	.	.	.
Thompsons Creek	.	.	.	.	.
NOTL	.	.	.	.	.
NOTL	.	.	.	.	.
NOTL	.	.	.	.	.

Sampling Station	1,2,3 - Trichlorobenzene	1,2,3,4 - Tetrachlorobenzene	1,2,4 - Trichlorobenzene	1,2,4,5 - Tetrachlorobenzene	1,3,5 - Trichlorobenzene
MDL	2	1	2	1	2
American Sites					
Buffalo River	.	.	.	.	.
Buffalo River	.	.	.	.	.
Buffalo River	.	.	.	.	.
Pettit Flume (site A)	.	250	70	100	10
Pettit Flume (site A)	75	130	40	10	5
Pettit Flume (site A)	80	130	40	10	6
Pettit Flume (site B)	120	210	80	20	.
Pettit Flume (site B)	115	190	70	20	8
Pettit Flume (site B)	100	175	60	20	5
Gratwick/ Riverside Park	.	.	.	.	.
Gratwick/ Riverside Park	.	.	.	.	.
Gratwick/ Riverside Park	.	2	.	.	.

Sampling Station	1,2,3 - Trichlorobenzene	1,2,3,4 - Tetrachlorobenzene	1,2,4 - Trichlorobenzene	1,2,4,5 - Tetrachlorobenzene	1,3,5 - Trichlorobenzene
MDL	2	1	2	1	2
Wheatfield	.	.	.	.	.
Wheatfield	.	.	.	.	.
Wheatfield	.	.	.	.	.
102nd Street	5	110	10	.	.
102nd Street	4	80	7	10	.
102nd Street	.	.	.	.	.
102nd Street	.	70	.	10	.
102nd Street	.	55	.	.	6
60th St. Sewer	.	5	.	.	.
60th St. Sewer	.	3	.	.	.
60th St. Sewer	.	3	.	.	.
Occidental 003	.	70	15	5	.
Occidental 003	15	75	.	.	.
Occidental 003	.	95	30	.	.
Gill Creek	.	2	5	.	3
Gill Creek	3	3	10	.	3
Gill Creek	7	4	30	3	.

Sampling Station	1,2,3 - Trichlorobenzene	1,2,3,4 - Tetrachlorobenzene	1,2,4 - Trichlorobenzene	1,2,4,5 - Tetrachlorobenzene	1,3,5 - Trichlorobenzene
MDL	2	1	2	1	2
Hyde Park	.	.	.	.	.
Hyde Park	.	.	.	.	.
Hyde Park	.	2	.	.	.
Bloody Run Creek	.	.	.	.	.
Bloody Run Creek	.	10	7	.	.
Bloody Run Creek	.	10	.	.	.

NOTL : Niagara-on-the-Lake
MDL : Method detection limit
"." Compound was below the method detection limit.

Table A4. Concentrations (ng/g) of Polycyclic Aromatic Hydrocarbons in Mussels introduced to the Niagara River for Three Weeks, 1989.

Sampling Station	Acenaphthene	Benzo(a) anthracene	Benzo(a) pyrene	Benzo(b) fluoranthene	Chrysene	Fluoranthene	Fluorene	Benzo (g,h,i) perylene	Indeno (1,2,3-cd) pyrene	Naphthalene	Phenanthrene	Pyrene
MDL	8	5	8	7	6	10	16	6	8	19	12	8
Canadian Sites												
Fort Erie	.	.	.	.	12	18	.	.	.	40	18	13
Fort Erie	.	.	.	.	8	12	.	.	.	34	13	10
Fort Erie	.	.	.	.	9	13	.	.	.	27	.	11
Thunder Bay, Lake Erie	.	.	.	.	.	.	.	.	.	29	.	.
Thunder Bay, Lake Erie	.	.	.	.	.	.	.	.	.	46	16	.
Thunder Bay, Lake Erie	.	.	.	.	.	.	.	.	.	38	13	.
Frenchmans Creek	.	.	.	10	12	.	.	.	.	35	46	.
Frenchmans Creek	.	.	.	.	9	.	.	.	.	.	.	.
Frenchmans Creek	.	.	.	.	10	.	.	.	.	.	.	.
Thompsons Creek	.	.	.	.	8	.	.	.	.	34	.	12
NOTL	8	.	.	.	10	.	.	.	.	35	.	.
NOTL	8	.	.	9	15	10	.	.	.	37	.	11
NOTL	.	.	.	.	10	.	.	.	.	43	.	.
American Sites												
Pettit Flume (site A)	.	44	57	334	269	107	.	79	70	.	27	149
Pettit Flume (site A)	.	36	32	211	226	87	.	73	.	18	16	127
Pettit Flume (site A)	.	45	41	270	246	97	.	86	54	.	21	135
Pettit Flume (site B)	.	33	29	170	247	154	18	.	.	19	37	187
Pettit Flume (site B)	11	114	72	540	571	316	37	106	77	19	69	375
Pettit Flume (site B)	..	56	40	235	278	110	.	72	43	.	23	145
Gratwick/Riverside Park	.	11	.	27	24	16	.	.	.	19	.	17
Gratwick/Riverside Park	.	12	.	32	24	17	.	13	.	.	.	20
Gratwick/Riverside Park	.	8	.	25	22	14	.	.	15	.	.	15
Wheatfield	28	12	.	17	39	28	31	.	.	141	60	32

Sampling Station	Acenaphthene	Benzo(a) anthracene	Benzo(a) pyrene	Benzo(b) fluoranthene	Chrysene	Fluoranthene	Fluorene	Benzo (g,h,i) perylene	Indeno (1,2,3-cd) pyrene	Naphthalene	Phenanthrene	Pyrene
MDL	8	5	8	7	6	10	16	6	8	19	12	8
Wheatfield	22	18	.	42	48	37	24	10	.	103	54	43
Wheatfield	12	.	.	16	23	18	15	.	.	27	36	21
102nd Street	.	6	.	22	20	19	.	.	.	.	.	18
102nd Street	.	.	.	11	16	18	.	.	.	.	.	16
102nd Street	17	.	.	.	19	20	.	.	.	69	37	18
102nd Street	20	.	.	.	12	21	21	.	.	104	48	17
102nd Street	30	.	.	.	13	24	.	.	.	144	63	14
60th St. Sewer	.	7	.	14	27	44	.	.	14	.	.	39
60th St. Sewer	.	.	.	.	24	29	.	.	.	19	.	25
60th St. Sewer	.	12	.	36	42	31	.	16	.	21	.	33
Occidental 003	20	8	.	.	86	30	14	.	.	82	56	34
Occidental 003	18	7	.	.	100	32	20	.	.	102	54	34
Occidental 003	17	9	.	60	129	36	.	7	.	84	46	42
Gill Creek	10	.	.	8	13	11	.	.	13	22	.	10
Gill Creek	8	.	.	13	14	14	.	.	.	23	.	12
Gill Creek	8	.	.	16	14	14	.	.	.	25	.	11
Hyde Park	28	.	.	.	.	16	17	.	.	125	72	10
Hyde Park	30	.	.	.	.	12	.	.	.	116	77	.
Hyde Park	12	.	.	.	.	12	.	.	.	72	40	8
Bloody Run Creek	.	.	.	.	.	11	.	.	.	53	40	.
Bloody Run Creek	20	.	.	.	5	16	.	.	.	91	53	10
Bloody Run Creek	22	.	.	.	.	10	.	.	.	95	54	.

NOTL : Niagara-on-the-Lake
MDL : Method detection limit

* Interpret with caution, indeterminante interference with analysis
"." Compound was below the method level detection limit.

Acenephthylene, Anthracene and Benzo(k)fluoranthene were not detected in any samples with the exception of the Pettit Flume which had one sample with 6 and 10 ng/g respectively. Dibenzo(a,h)anthracene was only detected in one sample at Occidental's sewer 003 at 9 ng/g.

Table A5. Concentrations (ug/g) of Metals in Mussels Introduced to the Niagara River for Three Weeks, 1989.

Sampling Station	Arsenic	Cadmium	Copper	Mercury	Manganese	Nickel	Lead	Selenium	Zinc
MDL									
Canadian Sites									
Fort Erie	0.41	0.92	1.5	0.01	120	0.4	0.6	0.46	32
Fort Erie	0.31	0.89	1.4	0.02	1400	0.5	0.7	0.46	55
Fort Erie	0.91	0.7	1.4	0.01	200	0.4	0.5	1	35
Thunder Bay, Lake Erie	0.48	0.74	0.99	0.01	850	0.4	0.6	0.47	35
Thunder Bay, Lake Erie	0.61	0.67	0.73	0.01	650	0.5	0.7	0.78	32
Thunder Bay, Lake Erie	0.49	0.73	1.3	0.03	980	0.5	0.7	0.54	34
Frenchmans Creek	0.25	0.74	1.8	0.01	1200	0.5	0.7	0.35	44
Frenchmans Creek	0.39	0.92	1.5	0.01	690	0.5	0.7	0.34	29
Frenchmans Creek	0.46	1	1.9	0.02	230	0.4	0.6	0.59	29
Thompsons Creek	0.28	1.3	1.3	0.03	760	0.5	0.7	0.37	44
Thompsons Creek	0.38	0.57	1.1	0.01	640	0.4	0.5	0.38	28
Thompsons Creek	0.29	0.61	1.1	0.01	970	0.5	0.7	0.31	32
NOTL	0.55	0.44	1.5	0.01	890	0.4	0.6	0.9	45
NOTL	0.31	0.53	1.5	0.03	610	0.4	0.8	0.42	30
NOTL	0.5	0.73	1.6	0.01	930	0.5	0.7	0.34	37
American Sites									
Buffalo River	0.54	0.48	1.9	0.02	280	0.5	0.7	0.44	20
Buffalo River	1.5	0.5	2.4	0.06	370	0.4	0.5	0.91	42
Buffalo River	0.44	0.9	2.1	0.02	460	0.54	0.7	0.31	61
Pettit Flume (site A)	0.48	0.85	5.1	0.03	1000	0.4	0.6	0.52	57

Sampling Station	Arsenic	Cadmium	Copper	Mercury	Manganese	Nickel	Lead	Selenium	Zinc
MDL									
Pettit Flume (site A)	0.44	0.62	3.9	0.08	220	0.4	0.6	0.47	71
Pettit Flume (site A)	0.59	0.68	11	0.03	1000	0.5	0.7	0.52	83
Pettit Flume (site B)	0.33	0.41	5.6	0.02	540	0.4	0.6	0.39	52
Pettit Flume (site B)	0.29	0.58	2.9	0.04	690	0.4	0.6	0.41	40
Pettit Flume (site B)	0.49	0.84	5.3	0.02	350	0.4	0.6	0.44	35
Gratwick/Riverside Park	0.35	0.85	2.1	0.02	860	0.52	0.7	0.33	37
Gratwick/Riverside Park	0.26	0.6	1.8	0.01	480	0.49	0.6	0.37	45
Gratwick/Riverside Park	0.32	0.76	1.2	0.02	890	0.4	0.6	0.37	29
Wheatfield	0.3	0.5	1.3	0.02	270	0.5	0.7	0.53	49
Wheatfield	0.6	0.74	1.7	0.13	370	0.5	0.8	0.46	61
Wheatfield	0.51	0.65	1.9	0.01	370	0.4	0.6	0.42	58
102nd Street	0.5	0.87	1.7	0.07	1600	0.42	0.6	0.49	42
102nd Street	0.45	0.4	1	0.15	490	0.4	0.6	0.43	21
102nd Street	0.57	0.79	1.3	0.08	410	0.38	0.6	0.34	50
102nd Street	0.17	0.6	0.86	0.09	170	0.4	0.5	0.37	54
102nd Street	0.03	0.59	1.6	0.11	990	0.5	0.7	0.35	51
60th St. Sewer	0.52	0.64	1.1	0.03	880	0.4	0.6	0.32	35
60th St. Sewer	0.42	0.85	1.9	0.04	900	0.4	0.8	0.35	49
60th St. Sewer	0.73	0.75	1.1	0.04	820	0.4	0.6	1.1	47
Occidental 003	0.5	1.1	2.5	0.02	1200	0.62	0.6	0.3	58
Occidental 003	0.48	0.61	2.2	0.02	970	0.4	0.6	0.32	44
Occidental 003	0.03	0.39	2.5	0.04	990	0.45	0.7	0.28	35

Sampling Station	Arsenic	Cadmium	Copper	Mercury	Manganese	Nickel	Lead	Selenium	Zinc
MDL									
Gill Creek	0.41	1.2	5.1	0.03	61	0.56	0.6	0.33	50
Gill Creek	0.32	0.76	3.5	0.03	130	0.66	0.6	0.39	28
Gill Creek	0.66	0.92	3.9	0.02	200	0.77	0.7	0.37	48
Hyde Park	0.04	1.1	1.1	0.02	1700	0.5	0.7	0.43	49
Hyde Park	0.12	0.98	1.4	0.01	1100	0.5	0.7	0.24	47
Hyde Park	0.11	1	1.4	0.04	210	0.5	0.7	0.33	40
Bloody Run Creek	0.46	1	1.5	0.01	1500	0.5	0.7	0.37	40
Bloody Run Creek	0.99	0.49	1.5	0.02	1400	0.5	0.7	1	32
Bloody Run Creek	0.4	0.81	1.4	0.04	1000	0.5	0.7	0.35	29
Balsam Lake Control	0.4	0.57	1.2	0.03	640	0.4	0.6	0.44	30
Balsam Lake Control	0.66	1.3	1.2	0.03	440	0.4	0.6	0.58	34
Balsam Lake Control	0.57	0.6	1.1	0.03	770	0.4	0.6	0.52	31